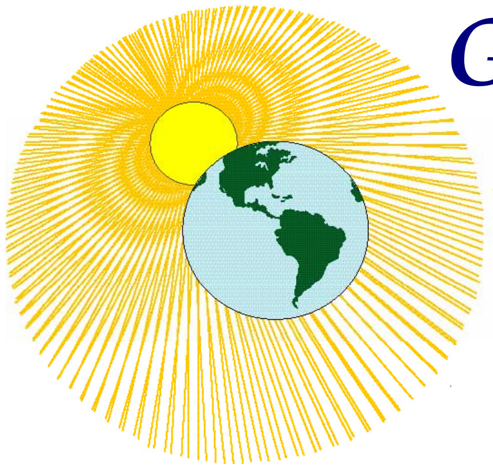
Lawrence Hall of Science



Global Systems Science

A Changing Cosmos

Teacher's Guide

Contents

Sources of Support

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NASA's Earth Science Enterprise (ESE) printed early editions of GSS books under a Memorandum of Understanding between NASA and the University of California at Berkeley. Nahid Khazenie provided assistance on behalf of NASA/ESE. The purpose of this agreement is to provide the broadest possible distribution to high schools throughout the United States at the lowest possible cost.

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To obtain latest revised editions of GSS books through University of California, Lawrence Hall of Science, please visit the GSS website:

http://www.lawrencehallofscience.org/gss/

Global Systems Science is an activity of the Lawrence Hall of Science, University of California, Berkeley. The director of the Lawrence Hall of Science is Elizabeth Stage.

Major portions of *A Changing Universe* are adaptations of *Hands-On Universe* high school modules developed by Jodi Asbell-Clark and Tim Barclay © 1995-2000 by TERC. HOU has been developed by staff at Lawrence Berkeley National Laboratory and Space Science Laboratories at the University of California at Berkeley, CA. The HOU curriculum was developed by TERC with contributions from the Berkeley staff, TRAs and pilot teachers. TERC is a nonprofit company in Cambridge, MA working to improve mathematics and science education.

The Adler Planetarium and Yerkes Observatory, with the tremendous effort of Vivian Hoette, has been instrumental in developing the HOU teacher training program.

Forward

In the most recent 40 years of our Universe, we have witnessed compelling growth in our understanding of the cosmos. In particular, we have made many exciting discoveries and measurements that have led us to know how galaxies, stars, and people evolved from the Big Bang. Much as the women and men of the first half of the century were the generation that unlocked the secrets of atoms, matter, and the fundamental methods and laws of physics, we are using the knowledge of physics to build a deep understanding of the Universe. We now have a model of the first few moments of the Universe and the consequent production of the fuel for stars -- Hydrogen and Helium. We have made significant progress in understanding how stars form. We have started to understand supernovae -- the explosive formation of probably most of the heavier chemical elements. And finally, we have found that many, many people find it important to gaze in awe at and to seek to understand the Universe. Many of us now seek truth and meaning in the understanding of our cosmic roots.

One could well imagine that our knowledge would continue to grow at a nearly exponential rate. But it is also clear and thrilling that for every detail of the cosmos we understand, we open a treasure chest of new, unanswered (or even unanswerable!) questions. I have been fortunate as a scientist to be surrounded with so much mystery and also to be blessed with so many tools to make sense of it all. These are exciting times for all.

We are lucky to have new computers, telescopes, software, telecommunications, and solid state detectors that can bring this adventure -- and the very workings of the quest -- into our classroom. Through Hands-On Universe™, we now have the ability to let teachers and students become explorers, some working along with our best scientists -- explorers of how we came into existence, of the fate of the Universe. Already, we have had two students and their teacher in Oil City, Pennsylvania catch the first light of a supernova. Already, we see many teachers and students discover the scientist within themselves by measuring and manipulating their images. Already we are taking the steps to create a community of teachers, students, scientists, and parents working together to undertake important personal explorations with this project. At the beginning of the semester, students name Albert Einstein as a scientist -- after a semester of using HOU, they name Einstein, but also their teachers and themselves as scientists.

HOU was created by teachers, students, and scientists who have seen and been inspired by this journey to the near infinite. To incoming teachers and students, I ask that you give free rein to your sense of wonder. I ask that you ask any question proudly, that you make models and speculations about what you are seeing. I ask that you endeavor to understand your place in the cosmos. This is important to me, and I believe your journey will become important for you. And I ask of you to take crucial steps -- start to measure the stars, the planets, the galaxies -- start to abandon yourselves to your curiosity -- start to ask questions to which there are no answers -- start to see the beauty in your images and in the origin of all things. Then, I am certain your lives will be forever changed, and you will walk in new light from the stars.

Carl Pennypacker

HOU's Success: An external evaluator has conducted surveys that show that students who have worked with HOU investigations are motivated to learn and retain scientific and mathematical concepts because of their use in the context of their investigations. Many students who did not think of themselves as scientifically inclined have come away from the HOU experience appreciating what a research scientist does, including feeling that they could pursue a scientific career for themselves. Startling discoveries and valuable science can occur when high school students are given access to professional telescopes as witnessed by two Oil City Pennsylvania High School students in the spring of1994. Melody Spence and Heather Tartara requested observation of M51, the Whirlpool Galaxy, during their investigation of spiral galaxies. A few days later they received a phone call informing them that they had captured the first light of SN1994i, the ninth supernova to be discovered in 1994. Ms Spence and Ms Tartara are co-authors in the official announcement of this discovery.

The Global Systems Science Series

Global Systems Science (GSS) is an interdisciplinary course for high school students that emphasizes how scientists from a wide variety of fields work together to understand significant problems of global impact. The *Teacher's Guide to Global Systems Science* provides an overview of the entire series and makes recommendations for how a course in this subject can be structured and presented. It is strongly recommended that teachers consult that guide before beginning a GSS course for their students.

The Teachers' Guide to GSS suggests that every course using this series begin with the unit *A New World View*, which introduces the entire field of global systems science, and presents four key ideas that thread through the entire series: First, the Earth has tremendously diverse environments, yet it is a single planet that we all call "home." Second, we can better understand the Earth if we think of it in terms of systems. Third, everything is connected to everything else. And fourth, the goal of global studies is to find out what we can do to sustain life on Planet Earth—now and in the generations to come.

A New World View can be followed by any other units in the series, depending on the purpose and context for the entire program.

Strategies for Computer Use

GSS has two types of computer/technology aspects:
(1) students can read the materials on computer display, and
(2) some investigations involve using computer software.

1. For reading GSS books:
   a. For in-class reading, show the reading material with a single classroom computer with large screen display (such as LCD projector) and have all the students read that display. This has a number of advantages such as needing only one computer, option of students reading the material aloud, or having immediate discussions of certain questions that might come up. You can have students silently read a page with the assignment to pick a sentence or two that contains a key idea that is especially interesting to them. Then have volunteers read their chosen sentences and explain why it is of special interest to them.
   b. For reading as homework, you need to find out how many students are able to use a computer at home for doing homework. For those students that have computers at home you can have students take the book home on CD-ROM or access the file from the GSS website. Students who do not have use of computers at home will need printouts of the specific pages that are the reading assignments.

2. For investigations using software:
   a. Reserve a computer lab and depending on the number of computers available, have one student per computer or pairs/groups of students share computers.
   b. Use a single classroom computer with large screen display. Have students take turns doing the "driving" with the whole class watching and discussing results.
   c. If most students have access to computers at home, assign the investigations as homework and loan CD-ROMs to the students to install the software on their home computers.
   d. Use a combination of any of the above approaches. For example, use strategy (b) for introducing the investigation and then (a) or (c) for student work.

Teaching Objectives

A Changing Cosmos

Goal 1: Students acquire beginning skills using HOU Image Processing software so they can start doing astronomy investigations.

Objective 1A: Students can interpret graphs and alternate data representations, from pixels on an image to plotted data,

Objective 1B. Students can measure sizes using Image Processing software toolsand compare sizes using ratios.

Objective 1C. Students make systematic use of technology to enhance image features for classification purposes.

Goal 2: Students gain familiarity with celestial objects and comprehend the signficance of those objects in terms of layout of the Universe and our place in the Universe.

Objective 2A: Students classify objects and identify trends and patterns within a data set.

Objective 2B: Students can describe lunar surface features, galaxy types, and a range of objects in the universe.

Objective 2C: Students can describe the phenomenon of supernovae.

Objective 2D: Students compare sizes of features ranging from lunar craters to the diameter of galaxies.

Goal 3: Students use mathematics to solve practical problems in astronomical settings.

Objective 3A: Derivation and application of functions and ratios within the context of a scientific technique.

Objective 3B: Students can analyze complex systems involving multiple factors.

Objective 3C: Students are familiar with the number scale and scientific notation, and use of appropriate units of measurement.

Objective 3D: Interpretation and transformations among various data representations beginning with pixels on an image, leading to angular size and then to linear size.

Objective 3E: Students use of ratios to convert from one type of measurement to another.

Objective 3F: Students use geometry to derive, validate and apply the Small Angle Approximation.

Goal 4: Students can do investigations.

Objective 4A: Students can exercise judgment on strong and weak conclusions to be drawn from collected data.

Assessment Tasks

Portfolios. General ideas for assessing student progress towards the goals and objectives of the GSS course are suggested on pages 19-23 of *The Teacher's Guide.- Overview of the GSS* We especially encourage the use of portfolios as a means of providing feedback to students and to demonstrate evidence of student progress to parents. Portfolios for *A Changing Cosmos* might include answers to the numbered questions posed in each chapter as well as written work done for each of the Investigations:

Using Star Maps (chapter 2)

CCD Camera Egg Carton Model (chapter 2)

Browsing the Universe (chapter 2)

Size and Scale of the Sun (chapter 3)

Parallax (chapter 4)

Inverse Square Law of Brightness (chapter 4)

Star Magnitudes (chapter 4)

Cepheids (chapter 4)

Observing Color and Temperature (chapter 5)

Measuring the Color of Stars (chapter 5)

How Filters Work (chapter 5)

HR Diagram of 47 Tucanae (chapter 5)

Finding Supernovae (chapter 6)

Eclipsing Binary Data Mining (chapter 6)

Tracking Jupiter's Moons (chapter 7)

Finding Exoplanets (chapter 7)

In addition to portfolios, we suggest that you use assessment tasks both before and after presenting the unit. The papers that students' complete before beginning the unit will help you diagnose their needs and adjust your plans accordingly. Comparing these papers to the students' responses on the same tasks after completing the unit will allow you to determine how your students' understanding and attitudes have *changed* as a result of instruction. Three tasks which we suggest be used for pre- and post- assessment are as follows:

1. Questionnaire

These questions are designed to determine how students' knowledge of key concepts have changed during the unit, and whether or not they have changed their opinions concerning personal actions and environmental issues.

2. Concept Map

Asking students to create a concept map before and after the unit is one way to determine which concepts they have learned and their understanding of the connections among these concepts. If students have not had experience in concept mapping, you might want to start them out with a hand-out showing an example (master on p. 8), a general idea of what they are to map, and starting word(s) to help get them started. Once they have had experience with concept maps, they can create them on blank sheets of paper (no photocopying required). Alternatively, they can use concept mapping software such as

Inspiration (http://www.inspiration.com)

Decision Explorer (http://www.banxia.com/dexplore/index.html).

CMap (http://cmap.ihmc.us/conceptmap.html - free for noncommercial use).

Compendium (http://compendium.open.ac.uk/institute/ - free download).

Omnigraffle (http://www.omnigroup.com/applications/omnigraffle Mac OSX)

Freemind (http://freemind.sourceforge.net/wiki/index.php/Main_Page - open source software for mind-mapping.)

Microsoft Draw (comes with Microsoft Office)

These two tasks fall along a spectrum from traditional to nontraditional ways of assessing student progress. The Questionnaire is a traditional way to elicit student understanding. It assesses students' abilities to express themselves as well as insights that they gained from the unit. The Concept Map is nonlinear. Students do not need to think in terms of sentences and paragraphs, and their ideas can flow more freely. Students who are more visual might be better able to show what they know on this task than on the Questionnaire.

Interpreting Student Responses

The tasks should be interpreted in terms of the objectives listed on page 4.

The Concept Map and Drawing Interpretation tasks are more loosely related to specific objectives. Comparing students' papers before and after instruction may show that they have learned more about some objectives than others, or that certain misconceptions persist while others have been corrected. Eventually, we hope to be able to provide sets of instructions (called "rubrics") to score student papers with respect to course objectives; but we do not yet have enough student data to do this.

In the meantime, we suggest that you pair students' pre-and post-assessment papers and compare them. With the list of objectives in mind, look for changes in the students' attitudes and understanding. As you look through your students' papers, you'll be able to jot comments for individual students concerning main points they may have missed, or praising them for their insights and ideas. After looking over all of the papers you will be able to write down some generalizations about what the class as a whole learned or did not learn during the course.

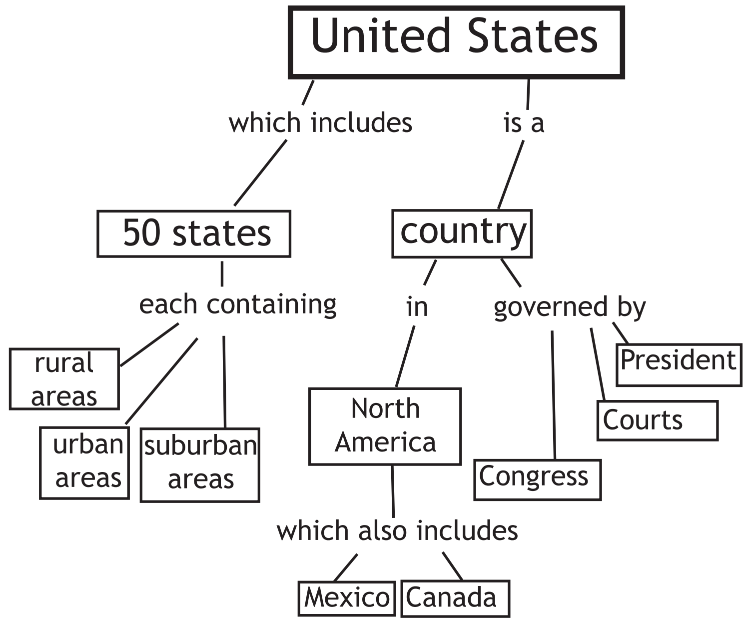
The three tasks are presented on the following pages. You may want to make two class sets of each of the tasks, using one color of paper for the pre-assessment measures and a different color of paper for the post-assessment measures.

Name____ Date_____________________

Changing Cosmos—Concept Map

A concept map is a way of displaying your knowledge about a certain subject area. It consists of a set of words in boxes representing the most important ideas. The boxes are connected by lines and words showing how the ideas in the boxes are related. For example, at right is a concept map about the United States.

Your task is to create a concept map about the Universe. Your concept map should show ways of thinking about the Universe as a system. Start with the word "Universe" at the top. (If you'd like more space, you can draw your concept map on the back, or on another sheet of paper.)



Universe

Cosmic Change—Questionnaires

The following pages contain questions that were developed by Kate Meredith, with substantive input from HOU staff and teachers, as well as input at annual HOU conferences. They are in four groups corresponding to the key National Standards for Astronomy content in high school.

Origin of the Elements - NSES: "Stars produce energy from nuclear reactions, primarily the fusion of hydrogen to form helium. These and other processes in stars have led to the formation of all the other elements."

Breaking down the standard:

i. Stars produce energy.

ii. Energy from stars comes in the form of electromagnetic radiation The energy coming from stars is from fusion as opposed to "burning" or fission.

iii. Fusion is the process by which nuclei of atoms are forces together under conditions of very high temperatures and pressure.

iv. Fusion of hydrogen to form helium releases a lot of energy.

v. Hydrogen was formed during the formation of the early universe all other elements are formed as a result of stellar processes.

vi. Supernovae and other non-explosive nuclear reactions in massive stars are responsible for the production of elements more massive than carbon.

Origin of galaxies - NSES: "Early in the history of the universe, matter, primarily the light atoms hydrogen and helium, clumped together. Billions of galaxies, each of which is a gravitationally bound cluster of billions of stars, now form most of the visible mass in the universe."

Breaking Down the Standard:

i. What is matter?

ii. Hydrogen and helium are the major elements in the early universe and still are today

iii. Matter tends to clump due to gravitational attraction

iv. Galaxies formed early in the history of the universe

v. There are billions of galaxies

vi. Most of the visible mass of the universe is found in galaxies

vii. Galaxies are groups of billions of stars that can be clustered in different patterns and have common characteristics.

Origin of the Solar System – NSES: "The sun, the earth, and the rest of the solar system formed from a nebular cloud of dust and gas 4.6 billion years ago. The early earth was very different from the planet we live on today."

Breaking down the standard:

i. The solar system began as a nebular cloud of dust and gas that began to collapse inward under the force of gravity.

ii. The sun formed at the center of the nebula which remained as a flattened disk spinning slowly around the sun.

iii. Most of the matter that remained after the formation of the sun was swept up by the gravitational pull of smaller pockets of matter orbiting the sun. These became the planets.

iv. The solar system includes the sun, nine planets, moons or satellites, asteroids, and comets.

v. The estimated age of the solar system is 4.6 billion years.

vi. The earth has changed significantly since its formation.

Origin of the Universe - NSES: "The origin of the universe remains one of the greatest questions in science. The "big bang" theory places the origin between 10 and 20 billion years ago, when the universe began in a hot dense state; according to this theory, the universe has been expanding ever since."

Breaking down the standard

i. The "big bang" is currently the most accepted theory of the origin of the universe.

ii. Details of the "big bang"

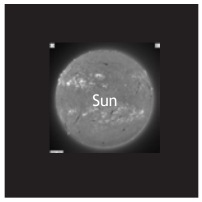
iii. Observational evidence exists for the "big bang" theory. The theory continues to change as new observations are made.

iv. Best estimates currently place the age of the universe at 10 – 20 billion years. These estimates are supported by scientific evidence.

Origin of the Elements

1. Which of the following stars gives off the most energy each second? (i)

A.


C.


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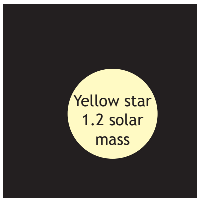

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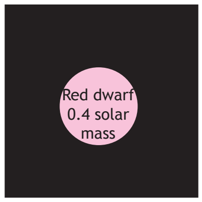
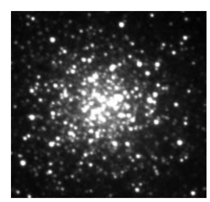


2. Which of the following is the best measure astronomers have of the amount of energy a star gives off? (i)
   A. The star's temperature
   B. The distance to the star
   C. How bright the star looks at night
   D. How big the star looks in the sky
3. Which of the following are examples of types of energy given off by a star? (ii)
   A. Infrared, Visible light, UV light, X-rays, Radio waves, Gamma rays
   B. Infrared, Visible light, Gravity waves, Radio, Chemical Energy
   C. Chemical energy, Infrared, Visible light, Sound, Radio waves
   D. Astrological energy, Infrared, Visible light, Radio waves, Sound
4. Where doesthe energy from most stars mainly come from? (ii)
   A. The fusion of hydrogen atoms to form helium
   B. The burning of hydrogen atoms in the core
   C. The splitting of large atoms in the stars core to form hydrogen
   D. The pressure of the hot gases in the star's interior
5. Which of the following conditions are required for fusion reactions to occur? (iii)
   A. Very high pressure
   B. An abundance of small atoms
   C. Very high temperatures
   D. All of the above
6. Approximately how long has the Sun has been giving off roughly the same amount of energy? (iv)
   A. 5 billion years
   B. 250,000 years
   C. 1 million year
   D. 3 billion years
7. What was the most common element in the early universe? (v)
   A. Hydrogen
   B. Helium
   C. Carbon
   D. Water
8. Whay can large atoms like uranium only be formed in supernovae explosions? (vi)
   A. Only supernovae produce sufficient heat and pressure to force large numbers of smaller nuclei together
   B. Only supernovae outshine all other stars
   C. Only supernovae last long enough for these atoms to form
   D. Only supernovae have enough mass to hold very large atoms together long enough for them to harden
9. Which of the following is an image of a supernova?

A.


C.


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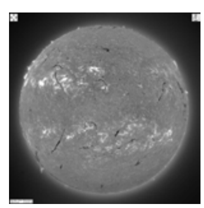

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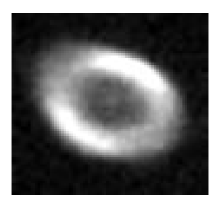
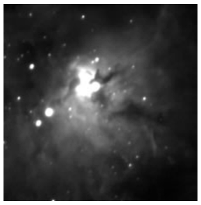
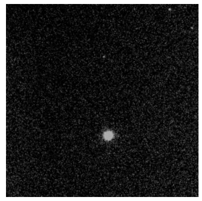
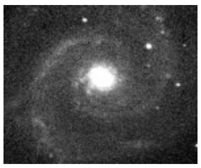


Origin of the Galaxies

1. Which of the following are examples of matter found in the universe?(i)

A. 

C. 

B. 

D. 

E. All of the above

2. What are the most common elements in stars? (ii)
   A. Hydrogen and helium
   B. Hydrogen and oxygen
   C. Iron and aluminum
   D. Water and air

3. What was a key factor in the formation of the galaxies? (iii)
   A. Gravity
   B. Reflection and refraction of light
   C. Swirling movement in space
   D. Electrical force

4. The Hubble Deep Field image covers a portion of the sky equal to the size of Roosevelt's eye on a dime when held at arm's length. What might lead you to conclude? (v, vi)
   A. There are billions of galaxies where most of the visible matter in the universe is concentrated
   B. Galaxies are not very common in the universe
   C. There are more stars in our own galaxy than there are galaxies
   D. None of the above

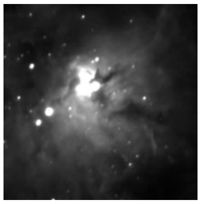
5. Edwin Hubble first observed individual stars within what had been thought to be clouds of gas inside our own galaxy. Which hypothesis does this observation support? (vii)
   A. Large groups of stars exist outside our galaxy
   B. The universe is much smaller than previously thought
   C. Clumps of tiny stars exist close to our solar system
   D. Some nebulae are lumpy

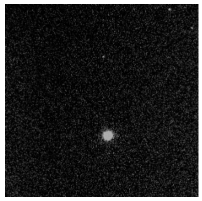
6. When astronomers first observed galaxies they called them nebulae because they looked like fuzzy patches in the sky. When were they sure they were separate from our own galaxy? (vii)
   A. They determined the distance to these objects
   B. They were able to see individual stars
   C. They observed the actual shapes of galaxies
   D. They were able to determine how fast they spin

7. Why is the image below NOT considered a galaxy? (vii)
   A. There are relatively few stars
   B. The stars are too young
   C. There is gas and dust present
   D. It is too large
   E. It is the wrong color

Origins of the Solar System

1. Which of the following images is the most likely source of new star formation? (i)

A. 

C. 

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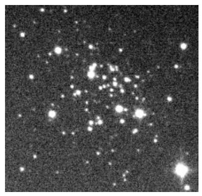
D. 

2. This image taken by the Hubble space telescope is of a forming star in the Orion nebula. Why were astronomers were very interested in this image? (ii)

A. Finding a disks of dark material around a star supports current theory about the formation of solar systems

B. Finding a young star in a nebula is very unusual

C. Finding a disks of dark material around a star disproves current theory about the formation of solar systems

D. Observing elongated stars supports current theory about how stars form.

3. Currently, the most popular theory of the formation of the solar system has gained support by Hubble Space Telescope images of disks of gas and dust around young stars in the Orion Nebula. According to current thinking, if we were able to observe these disks over the next million years, what is the next thing we would expect to see?(iii)

A. Clumps of material gathering with in the disk

B. The disk begin to glow

C. Nothing changes

D. Material in the disk will be drawn into the young star

4. In which of the following lists are the the objects in the correct order of INCREASING distance from the Sun? (iv)

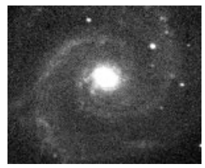
A. Asteroid belt, Jupiter, Kuiper belt, Oort Cloud

B. Jupiter, Kuiper belt, Asteroid belt, Oort Cloud

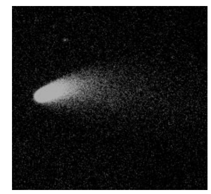
C. Oort Cloud, Kuiper belt, Jupiter, Asteroid belt

D. Jupiter, Asteroid belt, Kuiper belt, Oort Cloud

5. Which of the following objects is NOT part of our solar system? (iv)

A. 

B. 

C. 

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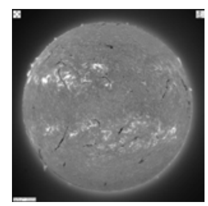
E. 

6. What is the age of the solar system? (v)

A. Approximately 4.6 billion years

B. Between 10 and 20 billion years

C. Approximately 5 million years

D. Less than 1 million

7. Scientists generally agree on the age of the solar system. What is that age based on? (v)

A. The radioactive decay of certain atoms in meteorites and moon rocks

B. The age of the oldest rocks on Earth

C. The rate of revolution of the Earth around the Sun

D. The number of craters on the moon

8. According to current theory about the formation of the solar system, which statement best describes Earth long ago ? (vi)

A. Smaller and hotter than it is today, with little oxygen in its atmosphere

B. Orbiting near Jupiter, before being deflected into its present orbit by a large asteroid

C. Part of another solar system

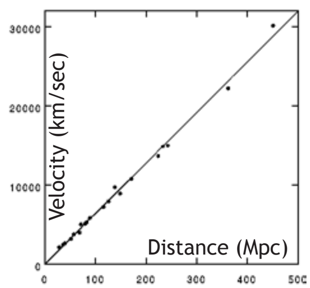
D. Colder and denser than it is today, with little carbon dioxide in it's atmosphere.

Origin of the Universe

1. The origin of the universe is one of the great questions in science. What is the the name of the most widely accepted scientific theory to explain how the universe came into existence? (i)
   A. The “big bang” theory
   B. The standard model
   C. The flat expansion theory
   D. The steady state model

2. Early in the twentieth century, Vesto Slipher, measured the spectra of many galaxies and found that most of them are shifted toward the red end of the spectrum. Which conclusion is supported by these observations?. (iii)
   A. Most galaxies are moving away from us
   B. Most galaxies are getting larger
   C. Our solar system is at the center of the universe
   D. Most galaxies are older than ours

3. Edwin Hubble discovered the relationship between the distance to a galaxy and the speed at which it is receding (moving away from us). This is known today as Hubble’s Law. This graph shows data supporting this law. Which of the following statements about the graph is FALSE? (iii)



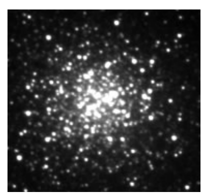
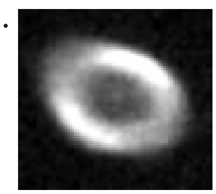
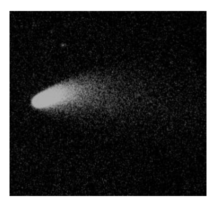
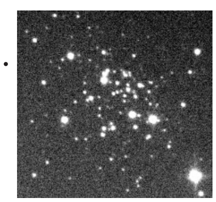
   A. The speed at which the galaxy recedes or moves away from us can never be zero
   B. The speed at which an object is moving away is roughly proportional to its distance
   C. The relationship between the speed of the galaxy and the distance is not exact
   D. The distance to an object can be approximately calculated by dividing its recession speed by a constant

4. Which of the following was most likely to have formed first according to the big bang model? (ii)
   A. Neutrons
   B. Hydrogen nuclei
   C. Helium atoms
   D. Hydrogen atoms

5. In the past twenty years the “big bang” theory had to be adjusted when astronomers made which of the following observations? (ii, iii)
   A. The expansion of the universe appears to be accelerating
   B. Some galaxies are not moving away from one another
   C. Most galaxy spectra are shifted to the red
   D. Galaxies are rotating

6. How old is the universe based on current estimates? (iv)
   A. Between 10 and 20 billion years
   B. Approximately 4.6 billion years
   C. There is no way to determine the age of the universe.
   D. Less than 500 million years

7. Based upon what you know about the following objects, which was most likely to have formed first in the universe? (iv)

A.

B.

C.

D.


8. Why are type I supernovae useful in estimating the age of the universe? Circle all that are correct. (iv)
   A. They can be used to gain more accurate distances to other galaxies
   B. They all have approximately the same absolute brightness
   C. They are very luminous
   D. The light we receive from them decreases predictably with increased distance

Page-By-Page Suggestions

Before you start

- At least a day or two before you begin *A Changing Cosmos*, distribute copies of the assessment tasks on the previous pages and ask your students to answer the questions. Explain that they will not be graded on these. The purpose is for them to show you what they already know so that you can plan the course accordingly.

Chapter 1

1. Cosmic Cataclysms

Pages 2-7

- This first chapter is mostly to just get students thinking about the cosmos in terms of events that could have real effects on their lives. You may choose to have a class discussion about students' feelings about these sobering possibilities of disaster from cosmic origins.
- Invite students to contribute their own knowledge and perspectives. Some might have read science fiction stories or seen movies that deal with some of these scenarios. Some may have read newspaper or magazine articles.
- Have students to a web search for "SpaceGuard" to find out more about current searches for near-Earth asteroids.
- There may be current Hands-On Universe high school student research in this field. See the HOU web site for latest info: http://lhs.berkeley.edu/hou

- Search for supernovae has also been an area of active HOU research by high school student teams. The HOU website will ahve news about any latest efforts in that area.

Construct a time line

It is always useful when dealing with geological ages to have a time line that will give the proper perspective of both human existence and the ages of the past. Have the student construct a time line on the chalkboard or a long sheet of butcher paper or masking tape placed on the wall. If the entire period of modern Homo Sapiens existed about 50 thousand years, and that is represented by 1 cm, then how far back on the time line did the dinosaurs become extinct? (65 million years ago, or 13 meters on the time line.) How long were the dinosaurs the dominant life form on the Earth? (For more than 150 million years, or 30 meters on the time line.)

- The students can experiment to simulate crater production. Wet clay or plaster of Paris of the proper consistency can model the Earth's surface. A large asteroid usually vaporizes after it strikes the surface. The students can experiment with drops of water, pebbles, balls of clay or pieces of plaster of Paris as simulations of an asteroid. Other possibilities include: splash water with hand; splash cornstarch mixture with hand. When a successful simulation is constructed, ask the students to vary the impact speed and examine the differences in the craters produced. Is there a relationship between the speed of their model asteroids and the size or shape of the craters?
- Class Debate: Divide the class into two groups: the Volcano Theory supporters vs. the Meteor Impact Theory supporters. Each group must provide evidence in support of assigned theory. Have the two groups read this chapter, jotting down arguments for their theory and against the alternative theory. Provide time for them to collect further evidence on the debate at a library. Finally, allow for a timed debate between the two groups.

What is kinetic energy? A briefing for advanced students

Derivation of the Equation for Kinetic Energy

Understanding the general idea of kinetic energy does not require any specialized knowledge; but understanding where the equation comes from involves some definitions.

Definition of average velocity (V_{ave})

$$V_{ave} = d/t$$

Velocity has the same definition as speed, but with the addition of direction. For a car moving at an average speed of 60 miles per hour, the above equation says that it would go a distance (d) of 60 miles in a time (t) of one hour.

When a large asteroid strikes the Earth, it is traveling at a very high initial velocity (V_I). When it strikes the Earth, it slows down and comes to a stop. So, it's final velocity (V_F) equals zero. This is an important period of time, because it is while the asteroid is slowing down and coming to a stop that it transfers all of its kinetic energy to the Earth!

In order to estimate the kinetic energy of the asteroid we'll assume that its average velocity—while the asteroid was ploughing into the crust and slowing down to a stop—was about one half of its initial velocity.

$$V_{ave} = {}^1/_2\,(V_I)$$

From these equations, we can find the distance that the asteroid travels into the crust:

$$d = {}^1/_2\,(V_I)\,t$$

Definition of acceleration (a) $a = (V_F - V_I) / t$

Acceleration means a change in speed. The most common example is a car, which might accelerate to 60 miles per hour in ten seconds. Its acceleration would be 6 miles per hour per second. The asteroid's acceleration is negative instead of positive, since it is slowing down. And, its final velocity (V_F) equals zero:

$$a = -V_I / t$$

Definition of force (F) $F = m a$

Force (F) is a push or a pull, and it can be measured by a spring scale. Here on the Earth, if we do not exert a continuous force, objects slow down and stop. That's because of friction. If we could eliminate friction completely, any force would make an object go faster and faster, as it is applied continuously. In space, for example, where there is no friction, if your rocket engines fire continuously, you will go faster and faster and faster. The above equation, known as Newton's Second Law, says that a given force (F) applied to a given mass (m) will accelerate it at the rate (a). In a sense, this important equation defines what we mean by force.

Definition of work (W) $W = F d$

It's difficult to believe, but in physics, doing math problems is not considered real work, but playing basketball is! That's because "work" has the special meaning of "force times distance." When you are sitting at a table you are not going anywhere, so d = 0. But when you are playing basketball, you are exerting a force on an object (the ball, and yourself) that moves a measurable distance.

Definition of kinetic energy (E) $E = W$

Energy of motion, or kinetic energy, is defined by the amount of work that an object can do on its surroundings. The asteroid is exerting a tremendous force when it collides with the Earth, and it continues to exert that force as long as it continues to plow through the crust. With the help of algebra that relates the above equations, we can find an equation that lets us estimate the energy by knowing the mass of the object and its velocity.

Start with: $E = W = F d$

Recall that: 1) $F = m a$ 2) $d = \frac{1}{2} V_I / t$ 3) $a = V_I / t$

Substitute: $E = F d = (ma) (\frac{1}{2} V_I / t)$

$$E = m (V_I / t) (\frac{1}{2} V_I / t) = \frac{1}{2} m V_I^2$$

So, kinetic energy $E = \frac{1}{2} m V_I^2$ where V_I^2 is the initial velocity of the asteroid before it begins to slow down, and m is its mass.

You may reinforce how the kinetic energy equation is used by having students do some problems that require its use.

Chapter 2

2. Astronomers' Tools

Pages 9-11

- Uncle Al's starwheels are practical tools for students to be able to find objects in the night sky. They also very useful for determing what objects are visible at a given time of year for students involved in research projects requiring requests for new images from HOU telescopes.

Answers to questions...

2.1 What Right Ascension line now points to the "S" in Southern Horizon? [correct answer 15]

2.2 What time is it now (still on June 1)? [correct answer 10pm]

2.3 What constellation just rose, almost due east? [correct answer Aquila]

2.4 What constellations are setting in the northwest? [correct answer Cancer and Gemini]

Rotate the Star Wheel FORWARD by another 15 degrees (= one hour).

2.5 What Right Ascension line now points to the "S" in Southern Horizon? [correct answer 16]

2.6 What time is it now (still on June 1)? [correct answer 11pm]

2.7 What constellation is rising, almost due east? [correct answer Capricorn]

2.8 What constellation is setting in the west? [correct answer Hydra]

Rotate the Star Wheel FORWARD one last time by another 15 degrees.

2.9 What Right Ascension line now points to the "S" in Southern Horizon? [correct answer 17]

2.10 What time is it now (still on June 1)? [correct answer midnight]

2.11 What constellation is rising in the northeast? [correct answer Pegasus]

2.12 What constellation is setting in the northwest? [correct answer Leo]

2.13 What constellation is near the zenith on New Year's Eve at 11 pm? [answer: Auriga]

2.14 In what month is the Big Dipper (Ursa Major) highest in the sky at midnight? [answer: March]

2.15 About what time is Leo setting (in the northwest) on the summer solstice (about June 21)? [answer 11 pm]

In the "Moving Planets" section, you may want to point out that exceptions to the general west-to-east drift of the solar system objects (planets and asteroids) in their orbits occur when the Earth in its own orbit is "overtaking" an object, at which time the planet seems to move in the opposite direction (east to west). This reverse movement is called *retrograde motion*.

If you have your students use the JPL ephemeris generator, mentioned at the end of the investigation, any "Table Settings" are possible, but for your first ephemeris, keep it simple—check only #2 Apparent RA&DEC and possibly # 29 Constellation ID.

Pages 15-20

- The *Browsing the Universe* investigation introduces various types of objects in the sky and encourages students to "play" with the software to create an image that is pleasing to them. It is particularly exciting, if a printer is available, for students to take home a copy of their work.
- The intent of this investigation is to have students discover the variety of different objects in the universe and explore questions about what they are and why they appear the way they do. Curiosity and hypotheses should be encouraged, and the inhibitions that are associated with "right" or "wrong" answers should be avoided. You can point out that no one is sure about the nature of astronomical objects, and even professional astronomers must start by "guessing" what they could be.
- In part I (Browsing), be sure that students understand that they should make a hypothesis about what type each object might be and why it looks the way it does, ***without*** doing any special research about the objects. One goal is for each student to ask "What is that object or feature ?" and choose to explore more about it.
- In part II (Galaxy Features), students need to do image processing to answer scientific questions about galaxy classification.
- This is the first investigation using the HOU Image Processing software, so be sure to have computers available and allow adequate time for students to familiarize themselves with the software tools.

Tips about the HOU IP software tools...

Min/Max. Since the shades/colors are divided evenly over the range between Min and Max, narrowing the range brings out more detail within that brightness range, but loses all detail outside the range. Strategies for adjusting Min/Max to bring out detail usually start as trial and error. Often this is frustrating and provides the motivation for finding another way. Using cursor readings is another way. Sampling the brightness of background pixels is a way to determine a new Min above the brightness of background. To find a new value for Max, sample the brightness of bright object pixels. This will distribute all the colors or shades of grey over the range of interest

Zoom increases the size of each pixel, and at Zoom 4 or 5 the whole image does not fit on the screen, fewer pixels fit on the screen, and this means the dimensions of the screen in pixels is less. The dimensions of the image, however, remain the same, as can be seen by scrolling. A higher zoom does not change the overall size of the image in pixels; it just doesn't all fit on the screen at the same time. Scrolling allows you to bring in the image, part by part, to check the pixel dimensions of the image.

Log scaling. This uses a logarithmic scale, rather than a linear one, for dividing the colors across the brightness range. It enhances detail in the dimmer parts of the image but at the cost of less detail in the brighter parts. The original versus log scaled displays look very different, but the brightness readings for the same features, as read in the Status Bar, are still the same. Just as the different palettes change the representation of the data on the screen but not the data itself, so also log scaling changes the representation but not the data itself.

Color Palette Bar. This question is included to provide an understanding of what the different colors or shades mean and how resolution depends upon the Min/Max range.

Slice. The different high points in a Slice graph mean different brightness - not to be confused with different heights. For the Moon image it is the sunny sides of the crater and the peak that reflect the sunlight and are therefore brighter. Knowing that the y-axis is brightness is important in learning to interpret Slice graphs.

- For a reference book, we suggest Burnham's Celestial Handbook (several years ago it cost $35 for all three volumes) or a Messier catalog with photos if you can afford them. A list of Messier objects by number and description is included in this Theme. Sky and Telescope Publishing has a poster of photos of the Messier objects, and a sheet that lists many Messier objects and shows where they are in the sky among the constellations. If reference material is not available, many libraries have astronomical catalogs, so it could be a homework assignment.

- On the next two pages, there are full scale sample worksheets for the Browse the Universe investigation, suitable for photocopying.

OPTIONAL INVESTIGATION: The Moon Match Unit in the original HOU Finding Features module requires some systematic use of the image processing functions to recreate a display. This is a good way to get students used to thinking about the options they choose and to study the effect of each image processing option.

Follow-Up and Assessment Ideas

1. Find images of other astronomical objects in a book or other reference material. Describe the choices made in representation of the image and determine which features in the image give clues as to what type of object it is. The emphasis in evaluation should be on the process of finding clues and forming hypotheses and conclusions, not on the accuracy of the answers.
2. Have one group of students retrieve a collection of images from the HOU archive or the Internet and use image processing tools to enhance features in the images. They need to keep a record of procedures used such as Log scaling and Min/Max values. Print out final versions of images. Challenge another group of students to try to recreate these final versions. Finally all students identify the type of object, and characteristics of the specific object if possible, for each image.
3. Students each make a presentation about an image they worked with, including a print-out or on-line demonstration. They should explain why they chose a certain palette, Min/Max values, and scaling and share a hypothesis about the object in the image.
4. Observe a collection of images of an astronomical phenomenon such as star formation or supernova remnants. Use image processing to identify common features found in all images. Make a prediction of what features are necessary results of the given phenomenon and request new images to test hypotheses.
5. Observe the Moon through a telescope or binoculars. Identify the craters you studied on images.
6. Keep a Moon Observation Journal: Observe the Moon from the same location and approximately at the same time each evening for a month (or as many nights as possible). Record the position and phase of the Moon on each night. Based on your observations:
   - Draw your estimate of the Moon, Earth, and Sun positions for each night.
   - Predict the time of rising and setting of the Moon each night.
   - Explain trends and patterns you observe.

Date: ______________ Name: ____________________________

Worksheet: Browser's Guide to the Universe

1. Detailed description of the appearance of each object.

browser1:

____

browser2:

____

browser3:

____

browser4:

____

browser5:

____

browser6:

____

browser7:

Date: ______________ Name: ____________________________

Worksheet: Browser's Guide to the Universe

2. My hypothesis on what type each object might be and why it looks the way it does.

browser1:

---

browser2:

---

browser3:

---

browser4:

---

browser5:

---

browser6:

---

browser7:

3. Settings for my favorite image:

Image file name: ____________________ Color palette: ______________________

Min/Max: _______________ Log scaling: yes no

GALAXY FEATURES

Date: ______________ Name: __________________

Answer Sheet

Galaxy 1: Display: Min: ___ Max: ___ Log Rough Sketch:

Name (see Galaxy Atlas): ____________________

Features used to identify galaxy: ______________

____

Galaxy Type:______________________________

❑ Spiral Arms ❑ Bar ❑ Ring

❑ Dust Lane ❑ HII Regions

❑ Companion Galaxy ❑ Foreground Stars

Galaxy 2: Display: Min: ___ Max: ___ Log Rough Sketch:

Name (see Galaxy Atlas): ____________________

Features used to identify galaxy: ______________

____

Galaxy Type:______________________________

❑ Spiral Arms ❑ Bar ❑ Ring

❑ Dust Lane ❑ HII Regions

❑ Companion Galaxy ❑ Foreground Stars

Galaxy 3: Display: Min: ___ Max: ___ Log Rough Sketch:

Name (see Galaxy Atlas): ____________________

Features used to identify galaxy: ______________

____

Galaxy Type:______________________________

❑ Spiral Arms ❑ Bar ❑ Ring

❑ Dust Lane ❑ HII Regions

❑ Companion Galaxy ❑ Foreground Stars

Galaxy 4: Display: Min: ___ Max: ___ Log Rough Sketch:

Name (see Galaxy Atlas): ____________________

Features used to identify galaxy: ______________

____

Galaxy Type:______________________________

❑ Spiral Arms ❑ Bar ❑ Ring

❑ Dust Lane ❑ HII Regions

❑ Companion Galaxy ❑ Foreground Stars

Galaxy 5: Display: Min: ___ Max: ___ Log Rough Sketch:
Name (see Galaxy Atlas): ____________________
Features used to identify galaxy: ______________
____
Galaxy Type:______________________________
❑ Spiral Arms ❑ Bar ❑ Ring
❑ Dust Lane ❑ HII Regions
❑ Companion Galaxy ❑ Foreground Stars

Galaxy 6: Display: Min: ___ Max: ___ Log Rough Sketch:
Name (see Galaxy Atlas): ____________________
Features used to identify galaxy: ______________
____
Galaxy Type:______________________________
❑ Spiral Arms ❑ Bar ❑ Ring
❑ Dust Lane ❑ HII Regions
❑ Companion Galaxy ❑ Foreground Stars

Galaxy 7: Display: Min: ___ Max: ___ Log Rough Sketch:
Name (see Galaxy Atlas): ____________________
Features used to identify galaxy: ______________
____
Galaxy Type:______________________________
❑ Spiral Arms ❑ Bar ❑ Ring
❑ Dust Lane ❑ HII Regions
❑ Companion Galaxy ❑ Foreground Stars

Galaxy 8: Display: Min: ___ Max: ___ Log Rough Sketch:
Name (see Galaxy Atlas): ____________________
Features used to identify galaxy: ______________
____
Galaxy Type:______________________________
❑ Spiral Arms ❑ Bar ❑ Ring
❑ Dust Lane ❑ HII Regions
❑ Companion Galaxy ❑ Foreground Stars

Investigation

Retrograde Motion

This is an excellent classroom activity for illustrating why a planet seems to go backwards against the background stars as Earth overtakes it in orbit.

Set up model as follows:

Sun is in center of room.

Earth orbit is created about meter or so radius, with 6 masking tape "X" positions marked for the first six months of the year

Mars orbit is created about 2 meters radius, with 12 masking tape "X" positions marked in approximately correct places in Mars orbit, corresponding to the 12 Earth months, keeping in mind that Mars orbit period is nearly 2 Earth years long. Arrange marks so that if you were to draw a line through the January position in the Earth orbit to the corresponding january position in Mars orbit, the line will hit the chalkboard or whiteboard.

Chalkboard or whiteboard represents the background stars: put some constellation patterns up on the board.

Have one volunteer stand at January in Earth orbit and a second volunteer at corresponding January position of Mars in its orbit.

A third volunteer goes to the chalkboard and follows instructions of the Earth volunteer, who tells where to place a mark on the chalkboard that lines up with Earth-Mars, to represent where Mars appears in the sky (chalkboard) from the viewpoint of Earth. Mark on chalkboard is labeled January.

New volunteers repeat steps 5 and 6 for the February positions in Earth and Mars orbits.

Repeat step 7 for March, April, May, June positions.

Discuss results--ask students if they can now explain what "retrograde motion" means? Have them describe how it happens.

Page 14 CCD Image Color Coding

Tim Spuck, a TRA and high school teacher in Oil City Pennsylvania wrote this activity. The impact comes when students decide on their own Keys for coloring the grid and then all the sheets are displayed. Some color codes will bring out the detail of the spiral galaxy better than others will, and discussion about this can help in understanding what is happening when students use different color palettes and different Min/Max ranges.

Some teachers have suggested giving some of the students only 3 colors instead of 4.

The faint object at the top middle of the grid requires some sort of "log" scaling to bring out its detail.

Master for larger color coding sheet is on the following page.

CCD Image Color Code

0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0	0	0	1	2	3	0	0	1	0	0	0	0	0	0	4	0	0
0	0	0	0	0	0	0	0	0	0	1	3	2	0	1	0	8	9	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	9	8	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	7	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	8	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	9	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	7	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	1	1	0	0	0	0	0	0	0	0	0	0	0	4	3	0	0	0	0	0	0	0	0	0
0	2	0	0	0	0	0	0	0	0	0	0	0	0	5	5	7	6	0	0	0	0	6	0	0
0	0	0	0	0	0	0	0	3	0	0	0	6	5	4	0	7	7	3	0	0	0	0	0	0
0	0	0	0	0	0	3	4	0	0	0	5	5	5	0	0	0	5	7	0	0	0	0	0	0
0	0	0	0	0	0	0	7	0	0	6	7	9	7	5	0	0	6	8	0	0	0	0	0	0
0	0	0	0	0	0	5	5	0	0	6	9	9	9	6	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	9	0	0	0	5	8	8	7	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	5	6	0	0	0	5	6	5	0	0	0	0	0	0	0	0	0	5	0
0	8	0	0	0	0	0	7	7	4	5	0	0	0	0	0	0	0	0	0	0	7	0	0	0
0	0	0	0	0	0	0	8	0	6	6	0	0	4	0	0	3	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Color Key

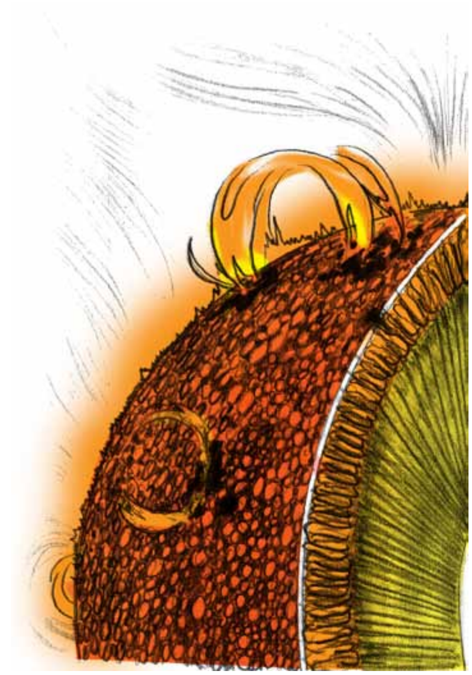
Brightness Key

Chapter 3

3. Cosmic Engines

Pages 22-24

This is an introduction to stars and the processes that power them, the Sun being our nearest example for study. Classroom discussion can elicit additional insights and clarifications on these issues.



Pages 25-28

Investigation: Size and Scale of the Sun

- The ulimate goal of this Investigation is to impress upon the students how huge the Sun is. To do wo, we equip students with the skills necessary to measure the size of an object in the sky using CCD images. Size is used in this context to describe a linear dimension such as diameter or width. The techniques used for measuring size begin with counting the number of pixels an object covers in a given dimension.
- When using the cursor to measure the width of features on images, keeping the imaginary line horizontal or vertical (using only the x or y coordinates), rather than at an angle, avoids using the Pythagorean Theorem. The Slice graph, however, gives distance in pixels, no matter what the angle.
- When analyzing the Eclipse image, students may realize that the dark circle is actually the Moon. Measuring the subtended angle of the Moon is a good approximation for the subtended angle of the Sun, as they observe in SA6: Using Angles to Measure Size. However, if they choose to estimate the width of the Sun in pixels from one edge of the corona to the other, this requires judgment on the definition of an "edge" of the corona. Answers in the answer key are using the Moon to get the subtended angle.
- A blank answer sheet for photocopying, if desired, is given at the end of this section.
- In order to translate the width of an object in pixels to a linear dimension across the sky, one needs to know the plate scale of the image and the distance to the object. The plate scale is the angle in the sky subtended by one pixel, and it varies from one CCD to another. Most of the HOU unit images were taken by the CCD camera on the 30" telescope at Leuschner with a plate scale of 0.67"/pixel, but older Leuschner images (taken with the old CCD) and images from other telescopes will have different plate scales. This information is usually provided in Image Info.
- Once the angle subtended by the object in the sky is known, the Small Angle Approximation can be used to determine the actual linear dimension of the object in the sky. This process is explained in the Discussion Sheet and Measuring Size with Images Unit.

Answers...

I d and e: Height of the prominince depends upon measuring screen distances by either:

cursor readings on the Slice line in the image, or

distance readings on the Slice Graph.

Using cursor readings, the prominence rises approximately 30 pixels above the rim, and the diameter of the sun is about 650 pixels.

For the ratio: pixel/pixel = km/km, the height of the prominence is around 68,000 km. A way in two steps is to first compute the number of km per pixel for the Sun and use this to find the answer.

3.1: about 5 Earths would fit between the rim and the top of the prominence.

3.2 The (x,y) cursor reading at the apparent top of the prominence should be greater. The two Slice graphs, however, are the same – they are a measure of the image data, which is always the same no matter what the Min/Max settings are. This question is included to point out how difficult it often is to determine the exact edge of something on an image.

IIa. Number of pixels covered by the Moon   about 650

IIb. Plate scale of eclipse1 image in degrees/pixel; the Moon covers an angle of approximately 0.5° in the sky

(0.5°) ÷ 650 pixels = 0.00077 deg/pixel

IIc. plate scale of the eclipse1 image in arc seconds per pixel

(0.00077 deg/pixel) x (2πrad/360 deg) x (206265"/rad) = 2.77"/pixel

IIIa. Width of Rori's screen ≈ 90 pixels

IIIb. Angle covered by Rori's screen

11 inches ÷ 81 inches = 0.136 radians

IIIc. Plate scale of the Rori image

0.136 radians x (206265"/rad) ÷ 90 pixels =   310"/pixel

IV-A. Width of Moon crater ≈ 72 pixels

Angle covered by crater in arc seconds

(0.99"/pixel) x 72 pixels ≈ 71"

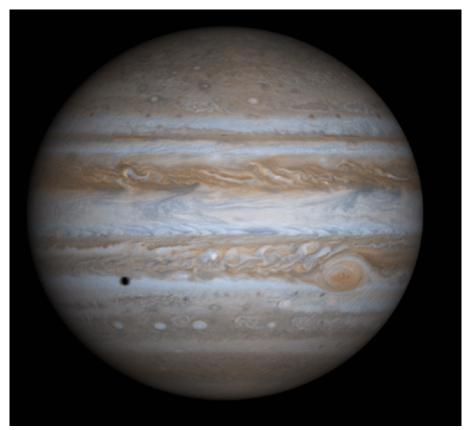
3.3. Actual size of crater in meters

d / (3.84×10^8 m) = 71" x (1 rad/ 206265")

d / (3.84×10^8 m) = 0.0003 rad

d = (0.0003 rad) x (3.84×10^8 m) = 1.3×10^5 m

Could a house fit in this crater?   yes



IV-B. Width of Jupiter ≈ 60 pixels

Angle covered by Jupiter in arc seconds

(0.67"/pixel) x 60 pixels ≈ 40"

Diameter of Jupiter in meters

d / (7.8 x 1011 m) = 40" x (1 rad/ 206265")

d / (7.8 x 1011 m) = 0.0002 rad

d = (0.0002 rad) x (7.8 x 1011 m) = 1.5×10^8 m_

3.4 Compare the size of Jupiter to the Moon crater. about 1000x bigger

IV-C. Width of Sun ≈ 650 pixels

Angle covered by Sun in arc seconds

(3.0"/pixel) x 650 pixels ≈ 1950"

Diameter of Sun in meters

d / (1.5 x 1011 m) = 1950" x (1 rad/ 206265")

d / (1.5 x 1011 m) = 0.009 rad

d = (0.009 rad) x (1.5 x 1011 m) = 1.4×10^9 m

3.5 Compare the size of the Sun to Jupiter.   about 10x bigger

IV-D. Distance to Crab Nebula in meters

6000 ly) x (9.5 x 10^{15} m/ly) = 5.7 x 10^{19} m

Width of Crab Nebula ≈ 150 pixels

Angle covered by Crab Nebula in arc seconds

(0.99"/pixel) x 150 pixels ≈ 149"

Diameter of Crab Nebula in meters

d / (5.7 x 10^{19} m) = 149" x (1 rad/ 206265")

d / (5.7 x 10^{19} m) = 0.0007 rad

d = (0.0007 rad) x (5.7 x 10^{19} m) = 4.1 x 10^{16} m

3.6. Compare the width of the Crab Nebula to the Earth-Sun distance: about 300,000x bigger

3.7a. Width of the spiral arms of M51 in lightyears

width in pixels = about 30 pixels

angle covered = (30 pixels) x (0.99"/pixel) = 29.7"

d / (3 x 107 ly) = 29.7" x (1 rad/ 206265")

d / (3 x 107 ly) = 0.00014 rad

d = (0.00014 rad) x (3 x 107 ly) = 4000 ly

3.7b. Width of M51

width in pixels = about 200 pixels

angle covered =

(200 pixels) x (0.99"/pixel) = 198"

d / (3 x 107 ly) = 198" x (1 rad/ 206265")

d / (3 x 107 ly) = 0.00095 rad

d = (0.00095 rad) x (3 x 107 ly) = 29,000 ly

3.7c. Compare the width of M51 to the Crab Nebula

M51: 29,000 ly x (9.5 x 10^{15} m/ly) = 2.7 x 10^{20}m

M51 / Crab = 2.7 x 10^{20} / 4.1 x 10^{16} m = about 7000x bigger

Date: _____________ Name: ______________________

Answer Sheet

Size and Scale of the Sun

I. How Big is that Prominence?

d. Height of the prominence in pixels:

Diameter of the Sun:

e. Height of the prominence in km:

3.1. How many Earths could fit under the prominence?

II: Measuring Plate Scale of an Image

a. Number of pixels covered by the moon:

b. Plate scale of eclipse1 image in degrees/pixel:

c. Plate scale of the eclipse1 in arcsecs/pixel:

III: Measuring Size on a CCD Image

a. Width of Rori's screen in pixels:

b. Angle covered by Rori's screen:

c. Plate scale of the rori image:

IV: Measuring the Size of Astronomical Objects

A. Width of moon crater in pixels:

Angle covered by crater in arc seconds:

Actual size of crater in meters:

3.3 Why a house could or could not fit in this crater:

B. Width of Jupiter in pixels:

Angle subtended by Jupiter in arc seconds:
Diameter of Jupiter in meters:

3.4 The size of Jupiter compared to the moon crater:

C. Width of Sun in pixels:

Angle subtended by Sun in arc seconds:

Diameter of Sun in meters:

3.5 The size of the Sun compared to Jupiter:

D. Distance to the Crab Nebula in meters:

Width of Crab nebula in pixels:

Angle covered by Crab Nebula (arc seconds):

Diameter of the Crab Nebula in meters:

3.6. Width of the Crab Nebula compared to the Earth-Sun distance:

E. 3.7a. Width of the spiral arms of M51 (in ly):

3.7b. Width of M51:

3.7c. Width of M51 compared to the Crab Nebula:

Follow-Up Activities and Additional Assessment Ideas

1. Choose an image with an object of known size. Find the size of another object or feature in the image.
2. Choose an image of an object for which the plate scale and distance are provided. Find the size of the object or feature in the image
3. Choose an image of an object for which the plate scale and object size is provided. Find the distance to the object in the image.

Chapter 4

4. Fathoming Huge Distances

Pages 30–31

Answer to question

4.1. Distance to Moon: 1.5 light-sed x 300,000 km/sec = 450,000 km
Actual distance to the Moon varies between 363,300 (perigee) and 405,500 (apogee), so the statement that the Moon is about 1.5 light-seconds away is very rough. It's off by at least 10%.

Pages 32-33

The parallax activity on p. 32 is based on work by HOU TRA Rich Lohman, physics teacher (now retired) at Albany High School in Albany, CA.

Answers to questions 4.2 through 4.5 are totally dependent on the circumstances of setup for the investigation. This is a good candidate for protfolio assessment.

On the following page is an investigation about parallax that can be done indoors or outdoors and uses at "Parallax Angle Measurer." Following that is an investigation on finding distance to a real asteroid by the parallax method. It was created by the Small Telescope Parallax Group:

Michael Richmond, RIT

Vivian Hoette, Hands-On Universe

Kaoru Kimura, Riken Institute of Japan

Larry Marschall and Christy Zuidema, Gettysburg College

Debora Katz, US Naval Academy

Mike Ford, Elk Creek Observatory

Lech Mankiewicz, Center for Theoretical Physics of Poland

Investigation

How Far Is It?

Materials

- Parallax Angle Measurer cutout sheet—scale piece (1/student + 2 for the teacher; photocopy master on p. 39)
- Distance Measuring worksheet (1/student; master on p. 40)
- 6 to 10 sheets of construction paper, $8^1/_2$" x 11", various colors
- Ruler or 8-1/2" x 11" sheet of paper (1/student)
- Scissors (1/student)
- Push pin (1/student)
- A bit of wine cork, eraser, wood, Styrofoam or other soft material, at least 1 cm thick, for a push pin to stick into (1/student)
- Five or six tape measures
- 2–3 rolls of tape
- Optional: Overhead projector and 3 sheets of acetate.
- Optional: Two or three tape measures

Before Class

1. Make one photocopy each of "Angle Measurer" cutout sheet for each student. The angle measurer will work best if you photocopy onto cardstock, though regular paper works adequately.
2. Cut bits of material that the push pin can be stuck into. Wine corks, big pencil erasers, or Styrofoam can be sliced up with a sharp kitchen knife into pieces about 1 cm thick.
3. Assemble a demonstration angle measurer yourself, following instructions in step 1.
4. Make 6 to 10 cardboard targets out of different colored construction paper. The targets can be stick people figures, cones, or other shapes. Making each one a different color will allow students to distinguish them easily. Place the targets among the students' desks so that the targets extend well above the height of the desks, 30 cm (a foot) or so. The targets may be taped onto desks or hung from the ceiling.

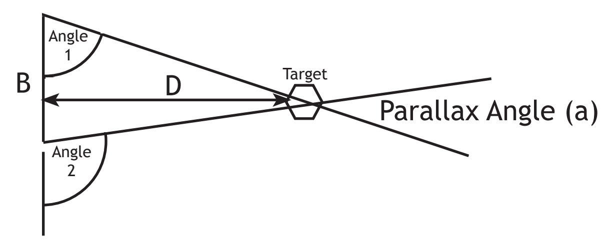
In Class

1. Have students make Angle Measurers:
   a. Cut out both pieces along the dashed lines.
   b. Fold up all the arrows along the dotted lines: the **reference** arrow on the scale piece, and the **target** and **eye** arrows on the pointer piece. A ruler is helpful here.
   c. Stick a pushpin through the "Pushpin" cross marks on the Pointer piece, the Scale piece, and then into the cork. The completed Angle Measurer should appear as in the figure on the cutout sheet and as your demonstration model. The pointer piece should be able to sweep along the angles of the scale piece.
2. Explain that each student is going to measure the distance from his or her desk to one of the colored targets in the room. A distant reference point will be the vertical line formed by the corner of the room farthest from the student. Ask each student to select a colored target object that is not too far

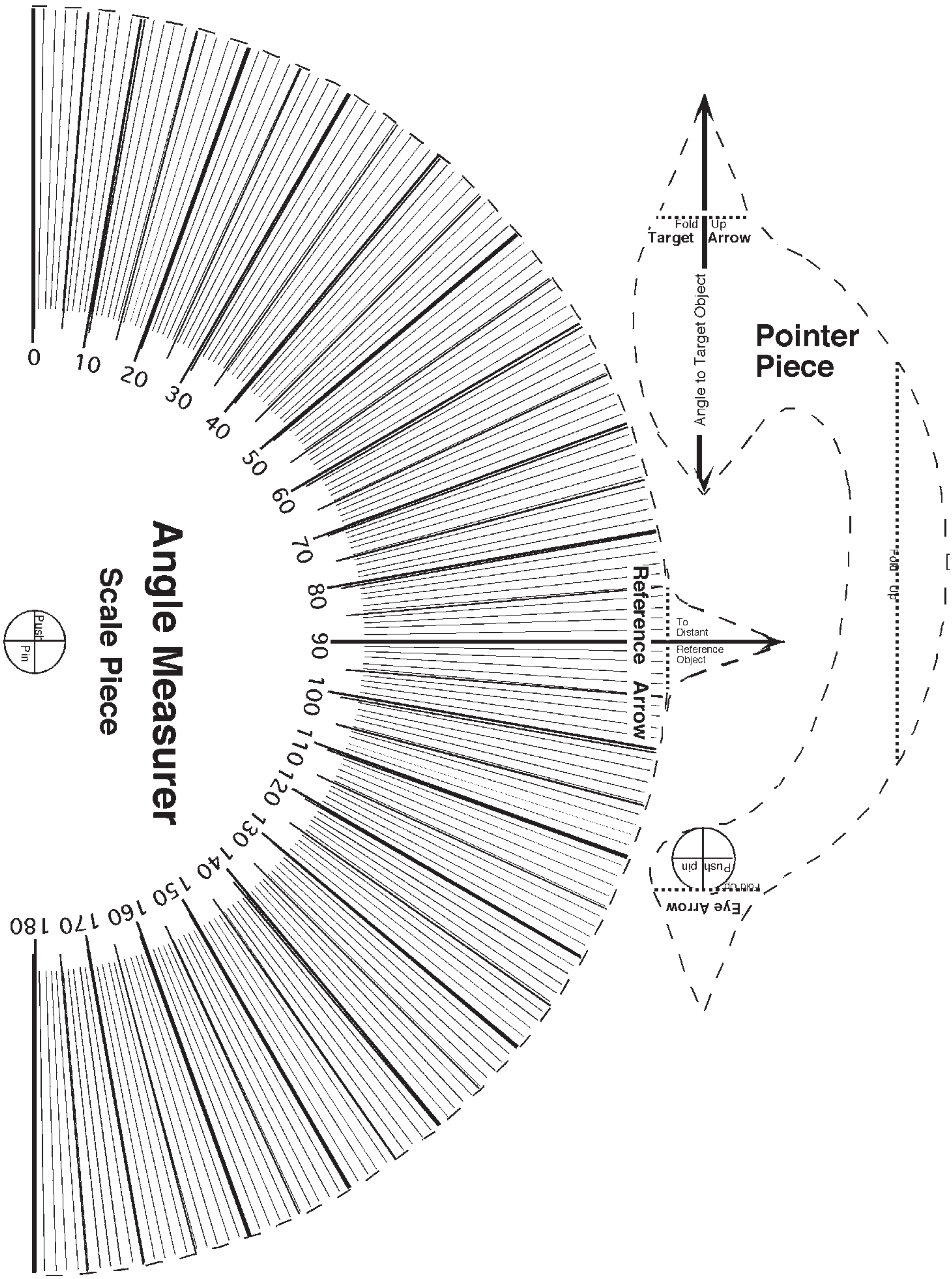
from them, but in the general direction of the corner of the room that is farthest from them.

3. Have each student make a baseline by taping a ruler or sheet of paper onto their desks. The baseline should be roughly perpendicular to the direction of the target and reference objects.
5. Have students measure the angle between the reference and target objects twice—one measurement at each end of their baseline. here's how:
   a. Put your Eye Arrow on one end of the baseline.
   b. Line up your Eye Arrow, the Reference Arrow, and the reference point (farthest corner of the room), thenpress the scale piece firmly to the desk with one hand, so that it does not move.
   c. Piivot the Target Arrow until it is in line with both the Eye Arrow and the colored target object, whose distance you are trying to measure. Only the Pointer Piece should pivot.
   d. Read the "Angle To Target Object" indicated on the scale and write that angle down as "Target Angle 1."
   e. Move the angle measurer to the other end of the baseline and repeat steps (b) and (c) to measure the 2nd "angle to target object." Write that angle down as "Target Angle 2."
6. Draw on the chalkboard the baseline and the target object and show how they form a triangle. Label Target Angle 1 and Target Angle 2. Extend the sides of the triangle and label the parallax angle as shown in the figure on this page. Explain that they can calculate the parallax angle by subtracting the larger angle from the smaller angle.
7. Have students to subtract the larger angle from the smaller angle and determine the distance to the target (the height of the triangle) which can be found by trigonometry...

   D = B ÷ tan (a).



Master for Angle Measurer on next page...


Angle Measurer
Scale Piece
Push Pin
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
Pointer Piece
Fold Up
Target Arrow
Angle to Target Object
Reference Arrow
To Distant Reference Object
Fold Up
Push pin
Fold Up
Eye Arrow

Investigation

Distance to Asteroid 1998wt

On March 4, 2005, telescopes from two different observatories in the United States took simultaneous images of an asteroid called "1998wt". The two observatories were Gettysburg College Observatory in Pennsylvania and Yerkes Observatory (24" telescope) in southern Wisconsin. They are approximately 970 km apart as the crow flies. This was not a new discovery of an asteroid, but the images were taken to demonstrate the use of parallax to determine the distance to a relatively nearby object in the sky. When you view these images you will discover a noticeable difference in the location of the asteroid against the background stars as you compare one set of images to the other set. A measurement of this "parallax shift" and the knowledge of the distance between the telescopes will allow you to calculate the distance to "1998wt".

Materials

- HOU Image Processing Software
- 6 Images:

  1998wt-050304-0245g, 1998wt-050304-0245y,
  1998wt-050304-0250g, 1998wt-050304-0250y,
  1998wt-050304-0255g, 1998wt-050304-0255y.

These images may be downloaded from http://spiff.rit.edu/richmond/parallax/1998wt/par_1998wt.html. The three images ending in "g" are from the Gettysburg scope. Those ending in "y" are from the Yerkes scope. The "050304" indicates the date, March 4, 2005. The "0245", etc. indicates the time the images were taken in Universal Time (UT). As you can see the images were taken simultaneously and with 5 minute intervals.

Procedure

1. Using the HOU-IP software open the three Yerkes images. The Yerkes images have a smaller field of view, so it's a bit easier to analyze these images. If you choose, try to locate the asteroid moving through this field by comparing the 0245 and 0250 images. Often an asteroid will have something of an elongated, sausage-like look. Once you have found the asteroid then see if you can find it in the 0255 image. If you're unsuccessful, or as a confirmation, use the procedure in step #2 below to locate the asteroid.
2. Use the "subtract" tool in the software to subtract 0250y from 0245y. Make sure you "Display result in a new window". Now you should be able to locate the asteroid's tell-tale trace with the white and black spots. Go back to the two original images to see if you can now see the asteroid. You will want to do that with image 0255y as well.
3. At this point it's a good idea to identify the x-y coordinates of the asteroid in the three images so you can locate it later in your procedure. The HOU software has a tool, Auto Aperture, which will help you do this. You can find this tool under the Data Tools menu, or locate the icon in the tool bar that looks like a small target. Just click on that button. Bring the cursor down onto one of the images and click on the asteroid. You will see a "Results" window open up that gives you 3 lines of information, including the coordinates of the asteroid. Those coordinates are in (x,y) format and in units of pixels. Record that information.
4. For the moment minimize the three Yerkes images. Open the three Gettysburg images, and go through the same analysis as you have done with the Yerkes images. You will notice the obvious difference that these images have a much larger field of view, so finding the asteroid by sight is quite difficult. You might bring up one of the Yerkes images to compare. Keep in mind, these telescopes were looking at the same star fields at the same time. You will also notice that the "stars" in the Yerkes images are farther apart, indicating a different Plate Scale.

5. At this point you may have decided to use "subtraction" with these images as well. In any case, use the Auto Aperture tool to measure the coordinates of the asteroid in the three Gettysburg images. Record that information.
6. Now you're at the point of measuring the parallax shift of the asteroid. If the two telescopes were identical and using the same cameras, then this process would be very simple. You would subtract one of the "g" images from one of the "y" images. Then you would measure the pixel shift and convert the pixels to an angle using the Plate Scale. It's not possible here since the plate scales and image sizes are different. So another procedure is called for. The following is a broad outline.
7. Using the HOU software open one image from each telescope. The two images must be of the same time (0245, 0250 or 0255). Shrink down the window of the "g" image so that you can place the two images, side by side, on the screen. Identify the asteroid in each image by using the Auto Aperture tool.
8. You now need to do a determination of how far the asteroid has shifted from one image to another, due to the two positions of the observatories. This is where you'll need to use your creativity. You have all the raw data you need in the images, along with the plate scales for each (given below). You'll undoubtedly want to make some approximations and/or some assumptions which may introduce some error. If you have time you can try several, perhaps more accurate, approaches. But take one approach all the way so you can calculate the distance to 1998wt.

You'll probably need to use a reference star, common to both images, that's reasonably close to the asteroid….but not necessarily. Initially you'll measure in pixels and, later, convert those pixels to an angle in arcsecs. Keep in mind that, because of the different plate scales, the pixel measurements between any two, fixed stars will be different, but the angular spacing will be the same. You might want to check that by using the plate scales below.

Plate Scales: Yerkes = 0.62 "/px.; Gettysburg = 1.09 "/px.

9. Now that you have the parallax shift in arcsecs, use the equation for parallax and calculate the distance to 1998wt. The baseline between the telescopes is ~970 km.

10. Convert the distance above to AU's. What do you notice about this number? Does it seem reasonable or surprise you? You might check on the following website for more information about this asteroid and further information on parallax: http://spiff.rit.edu/richmond/parallax/1998wt/par_1998wt.html

Page 34. A Law of Brightness

The materials listed for this activity include one suggestion for getting light readings from a light bulb. If you have a light meter from a camera in your lab, you may want to use it. However, you will have to create a scale to convert f-stops to intensities. This may add confusion since f-stops are on a logarithmic scale and you want linear readings for this activity to be effective.

Students should get readings which show that the light decreases according to the 1/r2 rule with distance. When plotting light reading vs. distance, the curve should be a parabola. The relationships

$B \propto D$ and $B \propto D^2$

can be ruled out immediately because they are direct proportions, rather than inverse. Students may be able to see a parabolic shape to their graph and rule out

$B \propto 1/D$ as well, which would be a straight line with negative slope. The point of squaring the distance and plotting light reading vs. distance squared is to get a straight line and then use the formula for a line to get an equation for light reading in terms of distance. Straight line equation: $y = mx + b$, where x refers to the scale on the x-axis, in this case x^2.

Page 35

Understanding magnitudes is particularly important for those students who will be doing research where they need to compare their data to that of other astronomers or to general reference material. Magnitudes are the most common system used for describing brightness of stars on optical images. Thus, although the system can seem antiquated and non-intuitive, it is presently core to optical astronomy. It is no coincidence that Hipparchus' original magnitude scale is logarithmic; that is the way the human eye behaves. Through the context of astronomical images, students may see there is a purpose and logic to logs.

Some students may have a hard time remembering that the magnitude scale is inverse. Brighter stars have lower magnitudes. Robert Burnham suggests in his observing handbook to replace the word "magnitude" with the word "class". One would expect a first-class star to be brighter than a second-class star.

Page 36

Investigation: Star Magnitudes

If you wish to have a preapred answer sheet for your students, there is master for photocopy in the following page.

Answers, Part I Star Magnitudes

How many times brighter is:

4.11. A 5th magnitude star than a 10th magnitude star: 100

4.12. A 7th magnitude star than a 17th magnitude star: 10000

4.13. A 3rd magnitude star than a 5th magnitude star: 6.25

4.14. A 3rd magnitude star than a 6.5 magnitude star: 25

4.15. A 12th magnitude star than a 22.5 magnitude star: 16000

4.16. Our sun (-26 magnitude) than a 15th magnitude star: 25,000,000,000,000,000

What is the magnitude of a star if:

4.17. It is 100 times dimmer than a 12th magnitude star? 17th

4.18. It is 10,000 times brighter than a 12th magnitude star? 2nd

4.19. It is 625 times brighter than a 11th magnitude star?............... 4th

4.20. It is 25,000 times dimmer than a -5 magnitude star? 6th

4.21. It is 100,000,000 times brighter than a 5th magnitude star?...... -15

Part II Comparing the Magnitudes of Stars

Advanced students may be asked to derive the formula for the difference in magnitudes for stars 1 and 2. Derivation is as follows:

Using the fact that Mag 6 stars are 100 times brighter than Mag 1 stars:

When $m_1 - m_2 = 5$, $B_2 / B_1 = 100 = (2.512)5$

Therefore a brightness difference of 2.512 corresponds to a magnitude difference of 1, and using m for magnitude and B for brightness:

Let $n = m_1 - m_2$

$B_2 = (2.512)n\ B_1$ ===> $B_2 / B_1 = (2.512)^n$

(note that this expression is correct whether B_2 is greater than, less than, or equal to B_1)

To solve for n, take the log base 10 of each side of the equation (log base 10 is commonly used by astronomers and found on most scientific calculators)

$$\log_{10} (B_2 / B_1) = \log_{10} [(2.512)^n]$$

$$\Longrightarrow \log_{10} (B_2 / B_1) = n [\log_{10} (2.512)]$$

$$\Longrightarrow \log_{10} (B_2 / B_1) \div \log_{10} (2.512) = n$$

$$\log_{10} (2.512) \approx 0.4 \quad \Longrightarrow 1/ \log_{10} (2.512) \approx 2.5$$

$$\Longrightarrow 2.5 \log_{10} (B_2 / B_1) = n$$

and by substituting $m_1 - m_2$ for n and reversing the equality:

$$m_1 - m_2 = 2.5 \log_{10} (B_2/B_1)$$

continued...

Date: ______________ Name: ____________________

Answer Sheet

Star Magnitudes

How many times brighter is:

4.11. A 5th magnitude star compared to a 10th magnitude star: _________

4.12. A 7th magnitude star compared to a 17th magnitude star: _________

4.13. A 3rd magnitude star compared to a 5th magnitude star: _________

4.14. A 3rd magnitude star compared to a 6.5 magnitude star: _________

4.15. A 12th magnitude star is compared to a 22.5 magnitude star: _________

4.16. Our Sun (mag = –26) compared to a 15th magnitude star: _________

What is the magnitude of a star if:

4.17. It is 100 times dimmer than a 12th magnitude star: _________

4.18. It is 10,000 times brighter than a 12th magnitude star: _________

4.19. It is 625 times brighter than a 11th magnitude star: _________

4.20. It is 25,000 times dimmer than a -5 magnitude star: _________

4.21. It is 100,000,000 times brighter than a 5th magnitude star: _________

An alternative derivation goes like this:

$B_2 / B_1 = (2.512)^n$ and $2.512 = (100)1/5$ and $100 = (10)^2$

===> $2.512 = [(10)^2]^{1/5} = (10)^{2/5}$ by substitution

===> $B_2 / B_1 = [(10)^{2/5}]^n$ by substitution

===> $\log_{10} (B_2 / B_1) = \log_{10} [(10)^{2/5}]^n$ take log of both sides

===> $\log_{10} (B_2 / B_1) = (2/5)(n)\log_{10} (10)$ laws of logarithms

===> $\log_{10} (B_2 / B_1) = (2/5)n$ $\log_{10} (10) = 1$

===> $(5/2)\log_{10} (B_2 / B_1) = n$ mult. each side by 5/2

===> $2.5\log_{10} (B_2 / B_1) = n$ $5/2 = 2.5$

and by substituting $m_1 - m_2$ for n and reversing the equality:

$$m_1 - m_2 = 2.5 \log10 (B_2/B_1)$$

When two stars are on the same image, the ratio of their Counts is equal to the ratio of their brightness so this can be rewritten as:

$$m_1 = m_2 + 2.5 \log (C_2 / C_1)$$

When the threshold is set to about 400 using Find, a box can be drawn around a small group of stars (rather than selecting the entire image which would give too many stars) and the dim stars can be found. Their brightness is around 20,000 Counts or lower. This yields a magnitude of about m(v) = 12.0.

Using Find with a box around about 1/16 of the whole image, there were 10 dim stars with brightness ranging from 2207 to 45430 Counts; magnitude from 13.6 to 10.4. In another sample, there were 9 dim stars with brightness ranging from 1601 to 55009 Counts; magnitude from 14.0 to 10.1.

For the first sample above, there was a difference in magnitude of 3.2. This is 2.53.2 or 15.6 times brighter. For the second sample, 2.54 equals 39 times brighter. The ratio of brightness Counts for these two samples is 14.28 and 34.36 respectively. The discrepancies are due to round off. Use 2.51 for the constant and the differences in Counts to 3 decimal places to make the ratios almost the same.

Part III Absolute Magnitude

Absolute magnitudes are used in optical astronomy to describe the intrinsic brightness of a star, independent of its distance away. This is related to the luminosity or power output of the star, but is unitless. The absolute magnitude of a star is defined as the apparent magnitude the star would have if it were 10 parsecs away, . This is an arbitrary definition that may confuse many students. It must be emphasized that the stars are not actually 10 pc away, generally they are much farther. This is just a distance chosen for convenience to make an absolute scale.

Answers:

4.24. Use algebra and the rules for logarithms to derive the following equation, called the distance modulus, for the difference between apparent and absolute magnitude:

$m – M = 5 \log (d) – 5$

Given the definition of absolute magnitude, use the definition of apparent brightness, the difference of magnitudes equation, and algebra to get the distance modulus.

Definition of apparent brightness, B:

$B = L/4\pi d^2$

where d = distance to the star

L = luminosity of the star

$B(\text{at } 10 \text{ pc}) = L/4\pi(10 \text{ pc})^2$ apparent brightness of star at 10 pc.from Earth.

===> $m - M = 2.5 \log [(L/4\pi(10 \text{ pc})^2) \div (L/4\pi d^2)]$ from the magnitude equation

===> $m - M = 2.5 \log [(1/(10 \text{ pc})^2) \div (1/d^2)]$ L/4π cancels

===> $m - M = 2.5 \log [d /(10 \text{ pc})]^2$ invert fractions

===> $m - M = 5 \log [d /(10 \text{ pc})]$ laws of logarithms

===> $m - M = 5 \log (d) - 5 \log(10 \text{ pc})$ laws of logarithms

===> $m - M = 5 \log(d) - 5$ $5 \log(10) = 5$

This equation is valid when d is in parsecs.

4.25. If a star is 2000 pc away and has an apparent magnitude of 7.0, what is its absolute magnitude?

$m - M = 5 \log(d) - 5$

$7 - M = 5 \log(2000) - 5 = 5(3.3) - 5 = 16.5 - 5 = 11.5$

$M= 7 - 11.5 = -4.5$

4.26. If the star measured in Part II is 1400 pc away, what is its absolute magnitude?.

$m(v) = 12.0$

$12 - M = 5 \log(1400) - 5$

$M= 1.27$

Pages 38-41

Cepheid Variable Stars As Distance Indicators

This unit uses the skills learned in the Photometry Techniques Unit to begin a real astronomy project. Classes can use this unit as preparation to doing their own Cepheid monitoring; e.g., requesting new images of other Cepheids and analyzing the results, or using the example set of images provided here to study concepts such as graphing, harmonic motion, and thermodynamics. The pulsation of Cepheids is a fascinating astronomical phenomenon that is rich in Physics concepts and also plays a key role in measuring the size of the universe.

Based on Leavitt's Period-Luminosity relationship, we can use Cepheids to measure distances quite confidently within our own galaxy. Unfortunately, there are many star clusters within our galaxy that do not contain Cepheids. For nearby galaxies where individual stars cannot be resolved, Astronomers measure light variations they see from regions of the galaxy and infer that these are caused by Cepheids.

When new techniques are developed to measure distances to star clusters or galaxies, they are generally compared to measurements to clusters and nearby galaxies based on Cepheids. Once a new technique is confirmed, it can be used to measure objects further away. In this way, Cepheids provide a solid lower rung to the distance ladder for measuring the size of the universe.

The thermodynamics that make Cepheids so interesting involve the pulsation of the star caused by heating and cooling of the gas. Most stars experience pulsations at each new evolutionary stage, but the pulsations dampen and the star reaches thermal equilibrium. In a Cepheid the pulsations remain periodic as the star overshoots the equilibrium position during each contraction and expansion. Sophisticated models and simulations have shown that this will occur when the convection layer of the star is positioned at a certain distance under the surface, so the primary heat transfer mechanism continues to switch between convection and radiation.

Cepheids

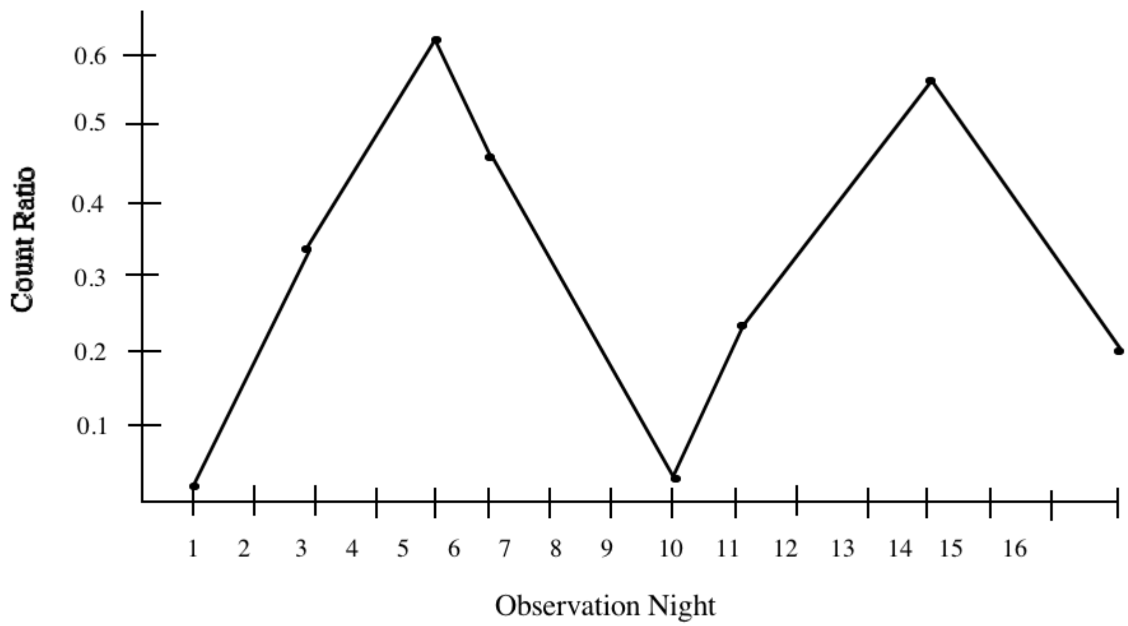
Answer sheet master for photocopy is at the end of this section.

I: The answers provided in the answer key are based on the images may06cep - may21cep. These images are manufactured to simulate a Cepheid variable star with a reference star in the same image. The original images were actually two sets of images: one set of a Cepheid with no other star in the field of view, and a corresponding set of a standard star observed at the same time. If you choose to use these images for classroom purposes, please make it clear to students that they are using images that are the sum of two images. This can be noted by some keen observers because the stars move around relative to each other in the images.

4.26. and 4.27.

	May06	May08	May10	May11	May14	May15	May18	May21
Counts of Cepheid	3488	1746	80907	48670	3603	72637	152711	61895
Counts of Reference	285847	5301	133451	111359	289890	289707	271794	285991
Count Ratio	0.01	0.33	0.44	0.61	0.01	0.25	0.56	0.22

4.28.



4.28. Period of the Cepheid: 8 days.

4.29. Luminosity of Cepheid in solar units: 2000-3000

4.30. Luminosity of Cepheid in Watts: 1.14 x 1029 W to 1.71 x 1029 W

4.31. Apparent Brightness of the Cepheid:

Avg. Count ratio of Cepheid to Reference = 0.3

and Apparent Brightness of Reference = 2.28 x 10-12 W/m2 ===>

Apparent brightness of Cepheid = (0.3)(2.28 x 10-12 W/m2) = 6.84 x 10-13 W/m2

The average Count ratio can be found either by estimating the middle of the cycle and finding the Count ratio there, or by finding the maximum and minimum Count ratio and averaging the two.

One form of the equation to get the apparent brightness of the Cepheid is:

$b(v)_C = (C_C / C_s) \times b(v)_s$ where $b(v)_C$ = the apparent brightness of the Cepheid star

$b(v)_s$ = the apparent brightness of the standard star

C_C/C_s = the average Count ratio of the Cepheid to standard star

There are other equivalent forms and it should be emphasized that form the student comes up with is fine as long as it gets the job done.

4.33. Distance to the Cepheid in meters:

Apparent Brightness = Luminosity $4\pi d^2$

===> Distance = $\sqrt{\text{Luminosity } 4\pi(\text{Apparent Brightness})}$

===> Distance = $\sqrt{1.14 \times 1029 \text{ W}4\pi(6.84 \times 10\text{-}13 \text{ W/m}^2)}$

to $\sqrt{1.71 \times 1029 \text{ W}4\pi(6.84 \times 10\text{-}13 \text{ W/m}^2)}$

===> Distance is from 1.15×10^{20} m to 1.41×10^{20} m

4.34. Distance to the Cepheid in light years:

Distance = 12000-15000 ly

Date: _______________ Name: ____________________
Answer Sheet

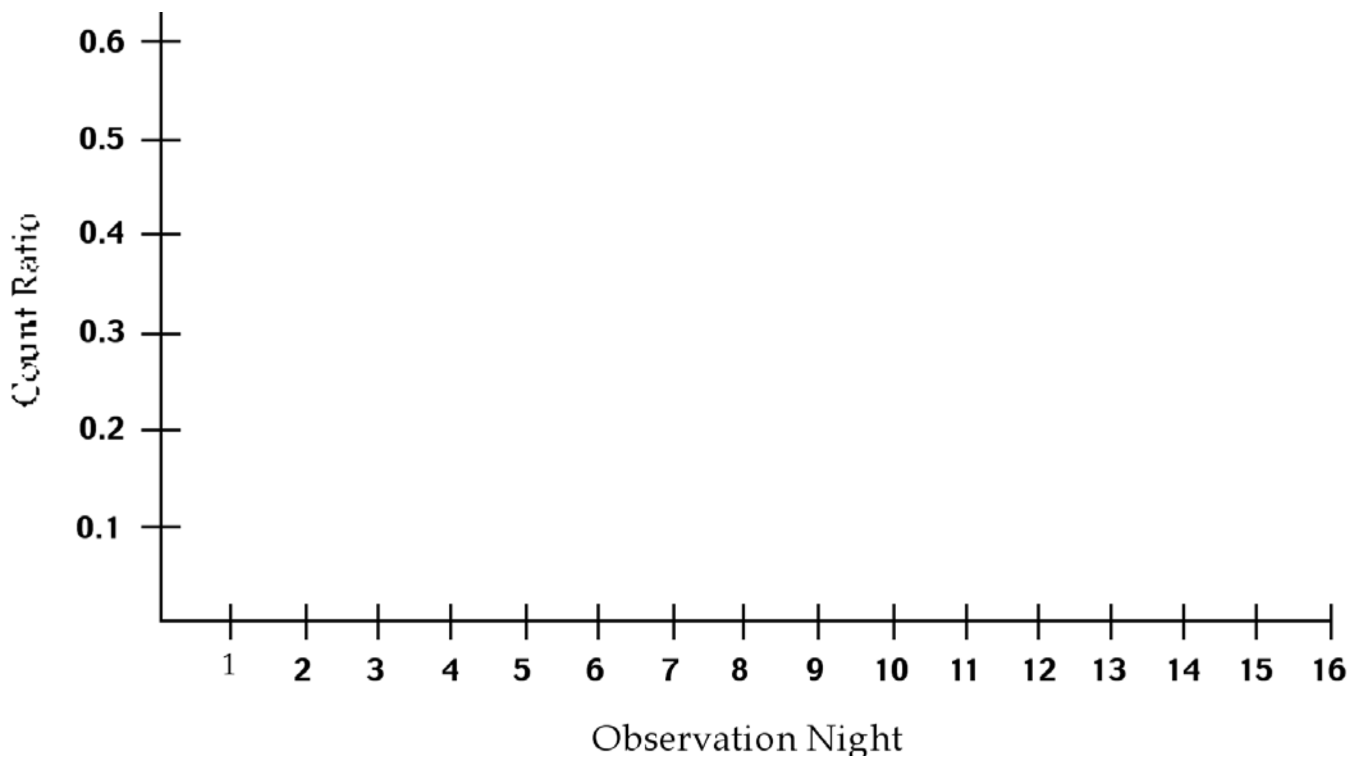
Cepheids

I: Plotting the Light Curve for a Cepheid

4.26. and 4.27.

	May 06	May 08	May 10	May 11	May 14	May 15	May 18	May 21
Counts of Cepheid								
Counts of Reference								
Count Ratio								

4.28. Graph.



4.28. Period of the Cepheids:

II: Finding the Luminosity of a Cepheid

4.30. Luminosity of the Cepheid in solar units:

4.31. Luminosity of the Cepheid in Watts:

III: Finding the Distance to a Cepheid

4.32. Apparent Brightness of the Cepheid:

4.33. Distance to the Cepheid in meters:

4.34. Distance to the Cepheid in lightyears:

Chapter 5

5. Color, Temperature, and Age

Pages 42-43

Observing Color and Temperature

Teachers have suggested that the best equipment for this demo is an aquarium light with a rheostat. You can also use a flame from a Bunsen burner or even a candle, but the burning gases themselves can affect the color of the light as does the temperature of the wick.

Answers

5.2. What color is the light when the rheostat is on high? blue

5.3. What color is the light at a middle setting? yellow

5.4. What color is the light at the lowest setting? red

5.5. At what setting do you think the light bulb is coolest? low

5.6. At what setting do you think the light bulb is hottest? high

5.7. What color would you expect a very hot star to appear? blue

5.8. Would a very hot star have a high or low B–V index? low

5.9. What color would you expect a relatively cool star to appear? red

5.10. Would a cool star have a high or low B-V index? high

5.11. Imagine you could double or even quadruple your distance away from a star. What would happen to the star's:

A. Apparent brightness? become less

B Luminosity? unchanged

C. Color? remain unchanged

Pagesw 44–45

Measuring the Color of Stars investigation

There is a note in the unit about Star B in Blue, but most students will probably miss it the first time. They must divide the Counts for Bstan2 by 3 because the exposure time for BStan2 is 3 times that of Btarg2, so it gathered 3 times as much light.

Here is an example of the calculations for Star1 and the table on page 35 provides the answers for the rest.

Use Auto Aperture to measure the Counts for the Btarg1 and Bstan1:

Counts of Btarg1 = 131801

Counts of Bstan1 = 46563

The apparent magnitude for Bstan1 is given as 8.0. Using the Brightness Conversion Table, this is equivalent to an apparent brightness of 5.83 x 10-12 Watts/m^2.

Use the fact that the Count ratio is equal to the brightness ratio, since the standard star was observed under identical conditions as the target star (with the exception of star 2 as mentioned above) to set up the following equation:

Let

Bt = apparent brightness of target star

Bs = apparent brightness of standard star

Ct = Counts of target star

Cs = Counts of standard star

Then Bt / Bs = Ct / Cs

so **Bt = (Ct / Cs)Bs**

For Btarg1:

$Bt = (131801/46563)\ 5.83(10)^{-12} = 1.65(10)^{-11}$

For Vtarg1:

$Bt = (90647/82695)\ 5.77(10)^{-12} = 6.32(10)^{-12}$

Going back to the Brightness conversion chart, you will find that these values give you the apparent magnitude of Btarg1 = 6.9 and the apparent magnitude of Vtarg1 = 6.9 as well.

Subtracting the apparent magnitude of Vtarg1 from apparent magnitude of Btarg1, gives you B-V= 0.0 for star1. Refer to the table provided within the unit to find that this B-V index corresponds to a color of White and surface temperature of 10,000K.

The reason we use magnitudes is because the B-V index is set up on the magnitude scale. All reference material will refer to these values. However since the magnitude scale is logarithmic and involves calculations that many HOU students are not prepared for, the Brightness Conversion Table allows you to work with the apparent brightness which is a linear scale and allows the use of simple ratios.

Master chart of Maeasuring the Color of Stars for photocopying is in the following page. Answer key:

	Star1	Star2	Star3	Star4
1. Counts of Btarg	131801	254410	54922	52706
Counts of Bstan	46563	88844÷ 3 = 29614	125794	74456
Counts of Vtarg	90647	215177	159633	40056
Counts of Vstan	82695	105220	139095	74744
2. Apparent Brightness of Bstan	5.83 E -12	1.94 E-12	7.06 E-12	1.47 E-11
Apparent Brightness of Vstan	5.77 E-12	4.80 E-12	3.65 E-12	5.77 E-12
3. Apparent Brightness of Btarg	1.65 E -11	1.67 E-11	3.08 E-12	1.04 E-11
Apparent Brightness of Vtarg	6.32 E-12	9.82 E-12	4.19 E-12	3.09 E-12
4. Apparent Mag of Btarg	6.9	6.9	8.7	7.4
Apparent Mag of Vtarg	6.9	6.4	7.4	7.7
5. B–V Index of Target	0.0	0.5	1.3	-0.3
6. Color and Temperature of Target	White 10,000K	Yellow 6,000K	Orange 4,000K	Blue 35,000K

Measuring the Color of Stars

	Star1	Star2	Star3	Star4
1. Counts of Btarg				
Counts of Bstan				
Counts of Vtarg				
Counts of Vstan				
2. Apparent Brightness of Bstan				
Apparent Brightness of Vstan				
3. Apparent Brightness of Btarg				
Apparent Brightness of Vtarg				
4. Apparent Mag of Btarg				
Apparent Mag of Vtarg				
5. B–V Index of Target				
6. Color and Temperature of Target				

Page 47

How Filters Work

The Great Explorations in Math and Science (GEMS) ***Color Analyzers*** Teachers' Guide has gexcellent activities that are quite useful at high school level, even though they are originally designed for middle school.

See http://www.lhsgems.org/GEM225&226.html

Lawrence Hall of Science 510-642-7771

University of California

Berkeley, CA 94720

GEMS Color Analyzers Teacher's Guide can replace steps 1–5 in the investigation on the following pages. It gives the science background on light, class handouts, and ways of assessing the students' understanding.

Investigation

Light and Color in Astronomy

Adapted from LIGHT, COLOR, AND ASTRONOMY, by Elizabeth E. Roettger (with advice from Vivian Hoette <Adler Planetarium>, David Malin <Anglo-Australian Telescope>, and others <especially from the Jet Propulsion Laboratory>) http://www.nthelp.com/eer/HOAcolorAstron.html

Students use colored filters to decode secret messages, look at rainbows through filters, observe what happens when colors are added together, experiment with colored objects in colored light, and learn how astronomers use colored filters to analyze images of objects in space.

Materials

- Color filters mounted on cards: Cut holes in paper or cardboard and tape filters on. The best filters are the Roscolux colors: Medium Red #27, Kelly Green #94 or Dark Yellow Green #90, and Primary Blue #80
- Secret Code sheets: These are (large) pieces of paper with colored shapes on them. The colors are such that when you look through a filter, some of the shapes look dark and some look light and even "disappear" against the white paper. Through the red filter, the dark shapes spell out a word or make a picture and the ligher shapes disappear. GEMS Color Analyzers has excellent secret message templates.
- Diffraction Grating: one comes with the LHS GEMS "Color Analyzer" book. They can also be purchased from Learning Technologies (http://www.starlab.com/). It's very delicate—fingerprints degrade it, so it's best to protect it by clear acetate. Also a cardboard frame allows you to stand the grating in front of the projector or hang it on the lens, as needed.
- Slide Projector with slit slide or overhead projector with cardboard slit: For slit slide, aluminum foil with a 1/4" wide slit cut in it works well. Mount diffraction grating in front of the projector's lens. Slit and grating should be vertically oriented to put a rainbow on the projection screen or wall.• Astronomy slides. See list and descriptions at the end of this investigation.
- Mirror

Procedure

Optional: GEMS Color Analyzers for steps 1-5

1. Using light. Point out that almost all of what we know about places beyond Earth comes from light. Astronomers have many high-tech detectors, but we have detectors, too - our eyes. We'll use our eyes and color filters, just like astronomers use cameras and color filters. Pass around the filter cards and suggest that participants use them to look around the room.
2. Secret code sheet. Hold up the first secret code sheet. Ask the students if they can read the message. Ask them how it looks through various filters. What color reveals the secret code? Show other secret code sheets. Ask why they think red works the best.
3. Why does red work best? Turn on the projector with the slit, and place the grating in front of the lens to make a rainbow; turn out the lights. Have students look through the filters at the rainbow. Point out where invisible IR and UV are. Walk through the colors with a white piece of paper, getting them to name the colors. Ask students what they see through each filter while you move a white piece of paper through the rainbow. Have them speak up when the edge of the paper becomes bright, and when it becomes dark again. Lead discussion towards students realizing that filters allow some color(s) of light to pass through, but block other colors.
4. Mix clolrsgreen. Use the mirror to throw colors from one side above, and then into,

colors on the other side. Point out that these colors are not single wavelengths of light. Look through filters at the plain and mixed colors. Note that you can take, say, pink, and tell what wavelengths it's made of. Color TVs work by mixing red, green, and blue to produce all the colors you see. If you look at a color TV screen through a magnifying glass, you'll see that the picture is made up of dots of 3 colors. Your eye blends them together.

5. Where is an object's color? What happens when you put a colored object in the rainbow? Use colored paper or objects (red and green apples, big patterns, the shuttle code sheet) and walk them through the rainbow. Hold one in red. Does it look any different than through the filter? If someone has on some brightly patterned clothing, ask them to walk slowly through the rainbow.
6. Color Astronomy. Project some astronomical slides. What do they look like through the different filters? What are we seeing? (Note: this is a good simulation of REAL astronomy: broad-band filter imaging -- in the daytime, in the classroom!) Notes on specific slides can be found below. Be willing to go back through the slides.

   Most of the slides we are using are actually 3 photographs or images added together -- each taken with black and white photographic film or plates, or with a black and white camera through colored filters. The three colors were then recombined to make these color images. It can take a great deal of skill to produce an image where the colors are balanced properly and each color is as clear as it can be.

Slides from the Astronomical Society of the Pacific (ASP) slide set called "Splendors of the Universe" except as noted.

Slide 12: The Helix Nebula, NGC 7293

Talk a bit about planetary nebula and what they are, since they show up again in the NGC 6822 slide. When the main fuel in a star (hydrogen) runs out, "the star may shed its outer layers to produce a beautiful planetary nebula like the one seen here." A planetary nebula doesn't have anything to do with a planet - it's a term we're stuck with historically. The gas is hot (heated by what's left of the star in the center), and so it glows. The chemicals in the nebula determine what the colors are.

Slide 8: The Cone Nebula

This is the real 'oh!' experience. What do you see through the red filter? Through the green? If you wanted to study stars, what might you do? What about this dark area - is it something or the absence of anything? How might you tell? (Hold your arm up to show where the dark region is, then have them look through the green filter.) Any difference in the density of stars? Have you ever been outside on a foggy day? Do distant objects disappear? Are they really gone? So what might be going on here?

The Cone Nebula contains both gas and dust. The red gas is hydrogen. The dark areas are generally dust blocking the light from the hydrogen gas and the stars beyond. There are stars hidden in the dust, and they tend to make the dust around them glow, so when you see a large, roundish glowing area, it's generally a hidden star lighting up the dust closest to it. If you were to see a wide-angle view of the area, you'd see that the dark cone shape is a finger of dust from a nearby dark (dusty) area.

Slide 5: Galaxy NGC 6822 in the Local Group

Last time the fuzzy stuff was red gas. Now the fuzzy stuff is blue stars, and you see stars through red. The blue stars are newer than the middle-aged yellow ones. If you wanted to study just new stars, what might you do? (For a lively audience: you're an astronomer. Your boss needs to know if this galaxy is just new stars, or if there are a bunch of old stars in the galaxy, too. How would you figure this out? ...note that whether people see the yellow stars that also form the galaxy depends on how bright your projector is - so respond to good reasoning rather than absolutes.) See anything else familiar? (Things that look like the planetary nebula we saw before -- actually these are called bubble nebulae, and they are much larger than planetary nebulae, and are caused by much bigger and brighter stars,

sometimes a whole group of them.)
NGC 6822 is a galaxy that's relatively close to us (close to 2 million light years). The newer, blue stars form a slightly different pattern than the older, yellow stars. The latter form a fairly smooth ellipsoid (flattened ball-shape), and the new stars form a somewhat irregular shape.

Slide 10: Dust Cloud and Open Cluster NGC 6520

What's happening here? Is there a hole in space? Are stars absent in that direction out to infinity? Do you see the brownish stars near the edges of the dark region? Have you ever looked through polluted air? Where are the blue stars relative to the dark area? (This assumes the blue stars are clustered together in space; since some are visible in the dark area, they must be in front.)
Old stars tend to be yellowish, young stars bluish. Here is a cluster of young stars (NGC 6520). They're in front of most of the yellow stars. There's also a dark cloud (called Barnard 86) blocking the light from the distant stars (some of the blue stars are in front of it). Around the edges (where the cloud is thinner), it doesn't block all the light, and the stars behind seem faint and brownish. The cloud may be what was left after the stars formed.

Slide 14: The Horsehead Nebula in Orion

(Kids tend to say what this looks like - a dinosaur or dragon or horse.) Is this some cosmic symbol that humans are not the most important beings? The red is gas, but what is the horsehead? If you weren't sure, could you use your filters to check? Look through green and compare the density of stars in the two areas. What does this mean? Is the shape "something" or "nothing"? Right - there's something there (it turns out to be dust) blocking the starlight. See this blue at the bottom? There's a star inside that dust, lighting up the dust in this area.
The red part is glowing hydrogen gas. The darkness is a cloud of dust obscuring the gas, stars, and galaxies behind it. The horsehead is a tendril of this cloud of dark dust. (I use my hand to throw a similar shadow -- arc it while describing the motion of the tendril.) Because there's no light shining on it, you don't see the dust, only its effect on the other light. However, there is a star buried in the dust and lighting up an area of it - the blue, roughly round area (NGC 2023) is dust lit by an imbedded star.

JPL P-41491 Moon, false color

What object is this? This is not what it would look like to your eyes. It's called (surprise!) false color. Several images were taken through different colored filters, then assembled - but not to simulate the true colors. The colors were exaggerated. The different colors show different kinds of surfaces. Still don't know what it is? Maybe the next slide will help...

(ASP) The Planetary System, slide 13, the Moon

Pages 48-49

The Hertzsprung-Russell (HR) Diagram is a plot that allows determination of stellar type from a star's color and luminosity. The stellar type yields information about the mass, chemical composition, and age of the star. The surfaces of stars are considered to be blackbody radiators so they follow a Planck spectrum, meaning that their color indicates a unique surface temperature. The process for measuring the color of stars uses images taken through two filters. Students will use archived images of known stars to calculate the B–V index, which is obtained from the ratio of brightness through the B and V filters. The relationship between color and temperature is described and students find the temperature of each star.

In order to plot a star on an HR Diagram, its luminosity or absolute magnitude must also be known. The luminosity is proportional to the radius of the star squared and the temperature of the star raised to the fourth power. This means that very large stars can be relatively cool yet have high luminosity (red giants) while very hot stars can be very small and still be reasonably bright (white dwarfs). It is the interdependence of radius and temperature that provide the interesting ambiguity presented in this set of activities.

The investigation HR Diagram of 47 Tucanae is not written up as of Nov 2007...

Chapter 6

6. Dramatic Change in Stars

Pages 50-59

Searching for Supernovae

- The Berkeley Automated Supernova Search Project is the birthplace of HOU. Dr. Carl Pennypacker realized this exciting scientific project could be implemented in such a way that high school students would be active collaborators. The HOU Supernova Search program, in which classes adopt a group of galaxies to monitor for supernovae, is now becoming a reality.
- This section is designed to teach the techniques used both implicitly in supernova search software and also explicitly by scientists to discover supernovae. The techniques are the same ones used in searching for other variable brightness objects such as Cepheid Variable stars as well as for other objects in the sky such as comets and asteroids.

Pages 53-57

Investigation: Finding Supernovae

- Answer Sheet for photocopy is on the next page.
- Additional image processing tools not introduced in the Browse the Universe (introduction to image processing) are:

  Shift, Subtract, and Multiply in the Manipulation menu.

  Sky, Axes and Find in the Data Tools menu.

- The set of M51fake images, all of which are of galaxy M51, The Whirlpool Galaxy, have a bright 'new star' added, thus their name fake. The M51nor image is a normal image of M51.
- Section I, II, and III break down the steps involved in supernova discovery so that students work with them one at a time, each time using an image in which only that step is required in finding the supernova. The process may seem difficult at first, but the techniques are used repeatedly in every supernova discovery, so they beome routine. The same steps are used in asteroid and comet discoveries as well.
- The four images used in section IV are of supernova SN1990H, the eighth supernova discovered in 1990. In this section students work with all the steps together that are needed for searching, rather than breaking them down into one step per image as the previous sections do.

Section IV-1: What Can You Tell By Looking At A Single Image?

One example of settings to enhance the contrast is Min/Max = 895/1650 with no Log scaling. This is an example of settings that work - not the only answer. The point is to bring out the spiral arms but not whiteout the galaxy core.

Section IV-2: What Can You Tell By Looking At Four Images?

Examples of Min/Max settings to bring out the spiral arms, without Log scaling, are:

SNW: 895/1650 SNX: 1500/2400

SNY: 150/750 SNZ: 285/985

The supernova is the bright object at (192,256) in SNW. It is dimmest in SNX, which means this image must be either the first one taken, before the supernova appeared, or the last one, after it had faded away. In fact, it is the latter.

- When you use Tile to arrange windows, they are made smaller if necessary to fit all on the screen. To restore, click on

Date: ______________ Name: ________________________

Answer Sheet

Finding Supernovae

6.1. Supernova data for m51fake1:

6.2. Center (x,y) coordinates of my reference star in each image:

6.3. Shift of m51nor to match m51fake2:

right shift = up shift =

6.4. What happens if you do not align before subtracting:

6.5. Position and brightness data for the supernova in m51fake2:

6.6. What happens if you do not adjust for brightness differences:

6.7. Position and brightness data for the supernova in m51fake3:

6.8, Coordinates of candidates to be SN1990H.

6.9. Coordinates of the supernova (A, B, C ...):

6.10. What I think is the proper order of SNW, X, Y & Z and why:

6.11. My Reference Star:

6.12. Normalization factors, using C for Counts.

Cx/Cx = ______ / ______ = 1   Cx/Cy = ______ / ______ = ___

Cx/Cw = ______ / ______ = ___   Cx/Cz = ______ / ______ = ___

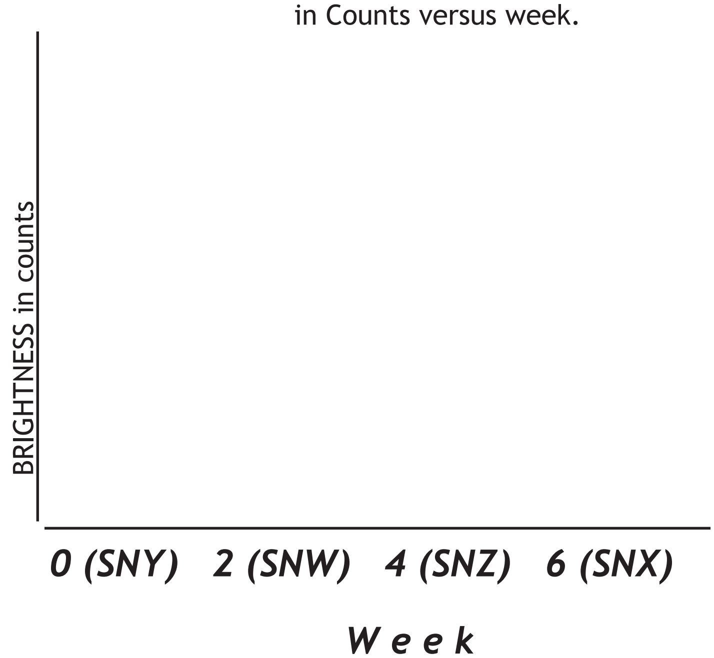
6.13 Brightness of the supernova in each of the images:

Supernova in SNW:

Supernova in SNY:

Supernova in SNZ:

6.14. Plot of brightness in Counts versus week.



the up-arrow or box, called the Maximize button, in the top right corner of the window. In order to have room to expand back to the original window size, the window needs to be away from the bottom and right edges of the screen. For these four image windows, you need to Maximize, or scroll, in order to see the bright star near the bottom right corner of the window.

Section IV-3: Subtracting Images to Find a Supernova

- Here are the background sky brightness values using Sky, and the coordinates of a reference star candidate at about 7 o'clock, using Axes. This is the information you need for the first two steps, Subtract Sky and Align.

SNW:	Sky: 943	Center: (118.87, 197.95)
SNX:	Sky: 1587	Center: (115.29, 114.98)
SNY:	Sky: 177	Center: (116.18, 111.00)
SNZ:	Sky: 335	Center: (94.95, 90.01)

- Here are the Auto Aperture Results for the reference star candidate at about 7 o'clock. These are the brightness values you need in order to calculate the Normalization factor.

SNW: Aperture: (119,107)	Brightness: 23520	Sky: 943
SNX: Aperture: (115,115)	Brightness: 28695	Sky: 1587
SNY; Aperture: (116,110)	Brightness: 19288	Sky: 176
SNZ: Aperture: (94,90)	Brightness: 21873	Sky: 333

A. Align/Shift. To correct for telescope aim, use the center coordinates from Axes to align each image with the Reference Image. For example, if the star in SNW at (118.87, 197.95) is the Reference Star, that same star in SNX is at (115.29, 114.98). With SNW in the active window, using Shift and entering "-3.58" for the X Offset and "+7.03" for the Y Offset, aligns SNW with SNX.

After aligning there are two corrections for observing conditions:

B. Subtract Sky to take out the background sky light.

C, Normalization — Multiply the image by the Brightness Ratio, called the Normalization Factor, to correct for haze or high thin clouds.

- To calculate the Normalization Factor:

$$\frac{\text{(Reference Star in the Reference Image)}}{\text{(Reference Star in the New image)}}$$

- Using the brightness Counts from Auto Aperture and again using the star in SNX at (115,115) as the Reference Star, the Normalization Factors are:

Cx/Cx = 28695/28695 = 1 Cx/Cy = 28695/19288 = 1.49

Cx/Cw = 28695/23520 = 1.22 Cx/Cz = 28695/21873 = 1.31

NB: These normalization factors are for revised versions, 9.1/96 and later. The normalization factors in the earlier versions are the inverses of the ones shown here.

D, Subtract Images

- Here are examples of Min/Max values to adjust the contrast in the subtracted images:

  For (SNW - SNX): -683/242

  For (SNY - SNX): -1000/250

  For (SNZ - SNX): -1300/1550. This adjustment can take a lot of trial and error.

- Look for a Supernova
- Using Find, and 'Perform Sky' and 'Sky + 4 * deviation' worked for the original SNW,X,Y,Z. Find does a search for bright objects with a pixel Count greater than the sky value plus four times the deviation in sky values. In the subtracted images,

however, this default setting finds too many objects. For these, Thresholds of 200, slightly below the Max settings, worked well.

• Using Find on the difference files, here are the values for the brightness of the supernova.

Supernova in SNW: 23273

Supernova in SNY: 34176

Supernova in SNZ: 5586

V. The shape of the light curve is important for classifying the type of supernova. SN1990H was a Type I supernova. More information about supernovae and further activities are included in the Brightness Theme section.

Follow-up Activities:

1. Join HOU Supernova Search Project and monitor some galaxies searching for new supernovae.
2. Design and implement an asteroid search project using HOU.

Pages 60-61

Show a nice eclipsing binary animation such as the ones at the bottom of Joel Hartman's homepage

http://cfa-www.harvard.edu/~jhartman/

Chapter 7

7. Planet-Star Systems

This chapter starts with characteristics of our own planet-star system (the Solar System) and lays groundwork for the next chapter on the search for extrasolar planets in other planet-star systems.

Pages 62-65

Question 7.1 is open ended—concerning what's wrong with the arguments of Greek philispoher Aristotle in refuting the Sun-centered system:

(1) If the Earth spun on an axis, why didn't objects fly off?;

Gravity is apparently much stronger than the "centrifugal force" (or pseudoforce) from the Earth's spin.

(2) If the Earth was moving (around the sun), why didn't it leave behind the birds flying in the air?;

Earth's gravity is able to make Earth carry it's atmosphere along with it.

(3) If the Earth was orbiting the sun, why didn't the stars appear to change their position since they were being viewed from a different perspective (the phenomenon of parallax)?

Stars are too far away to detect this effect.

Work on one of the Options below as directed by your teacher.

7.2 Assuming Earth's period is 1 year and it's orbit radius is about 150,000,000 km, using Kepler's 3rd law,

$$\frac{T_1^2}{T_2^2} = \frac{R_1^3}{R_2^3}$$

(a) what is Mars' orbit radius if it takes 687 days to orbit the Sun

$R^3 = (687/365)^2 \times [1.5(10)^8]^3$ km^3

$= 3.54 \times 3.375(10)^{24} = 11.95(10)^{24}$ km^3

$R = \sqrt[3]{11.95(10)^{24}}$ km

$= 2.285(10)^8$ km = 228,500,000 km

(b) how long is Jupiter's year if it's distance from the Sun is about 780,000,000 km?

$T^2 = [7.8(10)^8/1.5(10)^8]^3 \times 1$ yr^2

$= 5.2^3 \times 1$ yr^2 = 140.6 yr^2

$T = \sqrt{140.6}$ yr = 11.9 yr

Follow-Up Activities and Additional Assessment Ideas

3. Observe Jupiter through a telescope and find the Galilean moons. If possible do this over a series of nights and track the Moons visually. Based on your observations:

- Identify each of the Galilean Moons.
- Predict when each Moon will be in front or in back of Jupiter, called a transit of Jupiter or occultation by Jupiter respectively.

Pages 66-67

Here is a good place to delve into physics for a while and use Newton's lows in detail with exercises requiring F=ma as well as ones requiring

$F_g - G\,(m_1 m_2)/r^2$

Physics text books usually have suitable examples to use. Emphasize that acceleration and force are vectors. Newton's second law requires the direction of the force vector be the same as the direction of the acceleration vector.

Pages 68-72

For excellent physics enhancement, there is a document, Modeling Method with HOU for teaching Universal Law of Gravitation and Kepler's 3rd Law, at

http://www.handsonuniverse.org/hs/modeling/

The Introduction to that document states:

> *"This unit is the result of work in June 2004 by high school teachers expert in both HOU ... and Modeling Instruction Method (http://modeling.asu.edu, based at Arizona State University). The Modeling Method, grounded in Modeling Theory of Physics Instruction—educational research by David Hestenes and collaborators since 1980, corrects many weaknesses of the traditional science lecture-demonstration method, including fragmentation of knowledge, student passivity, and persistence of naive beliefs about the physical world. The Modeling Method promotes coherence by organizing thecourse around a small number of scientific models."*

TRACKING JUPITER'S MOONS investigation

On the following two pages are blan Answer Sheet masteres for photocopy id desired. Following that are answer keys.

HOU TRAs Rich Lohman and Jeff Friedman suggested the alternate subtract and add procedure for making a composite image of all six images. As students may have discovered, only adding the images results in over saturating Jupiter. Adding and subtracting in a more random way solves this problem, but it does make it harder to keep track of which moon is where when two are near each other.

If Jupiter is visible in the night sky for more than six hours, students may want to Request their own images as an alternative to using the set provided. There is an increased sense of ownership when working with your own images. In this case the images need to be aligned to correct for differences in telescope aim before doing any of the adding and subtracting. Use Axes to get the center coordinates for Jupiter in each of the images and Shift to align each image with the first one in the sequence. The Jup5 through 10 images are already aligned.

Date: ______________ Name: _______________________

Answer Sheet

Tracking Jupiter's Moons Unit

I Find the Moons:

7.3. My image settings:

Color Palette: _______________

Min: _____ Max: _____ Log scaling (y/n): ___

7.4. Which way each moon is moving (see my attached sketch or printout).

II Making a Double Exposure:

7.5. Why I think the moons are not twice as bright.

7.6. The double exposure. (See attached paper.)

III What Happens to the Moons During 6 Hours?:

7.7.

Image	Date	Universal Time
jup5	_________	_________
jup6	_________	_________
jup7	_________	_________
jup8	_________	_________
jup9	_________	_________
jup10	_________	_________

7.8 & 7.9. See attached sketch.

7.10. Fastest moon #: ____ Slowest moon #: ____

My reasoning in selecting these answers:

7.11. Direction and speed of each moon.

Moon #1:

Direction of motion relative to Jupiter:

Speed relative to Jupiter:

Moon #2:

Direction of motion relative to Jupiter:

Speed relative to Jupiter:

Moon #3:

Direction of motion relative to Jupiter:

Speed relative to Jupiter:

Moon #4:

Direction of motion relative to Jupiter:

Speed relative to Jupiter:

7.12. How I explain the apparent paradox.

7.13. A top view. (See attached drawing.)

IV: Interpret Your Data

7.14. Who Is Io? Identity each of the four moons.

Io:	#1?	#2?	#3?	#4?
Europa:	#1?	#2?	#3?	#4?
Ganymede:	#1?	#2?	#3?	#4?
Callisto:	#1?	#2?	#3?	#4?

7.15. How I decided on the name for each moon.

V: The Mass of Jupiter Unit

7.16. Earth's mass:

7.17. Distance and time data:

	jup5	jup6	jup7	jup8	jup9	jup10
Time:	_ _	_ _	_ _	_ _	_ _	_ _
Distance of:						
Moon1	_ _	_ _	_ _	_ _	_ _	_ _
Moon2	_ _	_ _	_ _	_ _	_ _	_ _
Moon3	_ _	_ _	_ _	_ _	_ _	_ _
Moon4	_ _	_ _	_ _	_ _	_ _	_ _

7.18. Plot of pixel distance of each moon from the center of Jupiter versus the time of day:

7.19. What the plot represents:

7.20. Estimate of the maximum distance for the moon that is at its turn-around point:

7.21. Value in radians:

7.22. Radius of the moon's orbit in kilometers:

7.23. Period of the moon:

7.24. Estimate of % possible error in my value for the period:

How I made this error estimate.

7.25. Mass of Jupiter from the equation:

$$M_J = \frac{4 \pi^2 D^3}{G T^2}$$

7.26. Currently accepted value for the mass of Jupiter:

% Difference =

7.27. Design for an experiment to obtain a more accurate value for the mass of Jupiter.

Answers:

I Find the Moons and
II Making a Double Exposure

Here is an example of contrast settings for the composite image of the moons after adding #6 to #5, subtracting #7, and continuing to add and subtract:

Min/Max: -300/800 and Log Scaling: No.

III: What Happens to the Moons During Six Hours?

7.3.

Image	Date	Universal Time
Jup5	23/04/1992	04:01:02
Jup6	23/04/1992	05:01:20
Jup7	23/04/1992	06:01:10
Jup8	23/04/1992	07:01:12
Jup9	23/04/1992	08:01:17
Jup10	23/04/1992	09:01:24

An image Header contains a lot more information than just the date and universal time. The Observatory and observer names are interesting to note. Information that is used in later modules include filter, Right Ascension, RA, and Declination, Dec, and the plate scale.

Making a sextuple image. When Adding or Subtracting an image, the 'File from disk' option does not work if the file is a compressed one, a .fth file.

One must be careful to keep track of the sequence when making a sextuple image. Starting with Jup5, subtract Jup6, add Jup7, subtract Jup8, add Jup9, and subtract Jup10. The result using the Grey palette is a series of alternating white and dark moons corresponding to each moon's position on its orbit as taken from the six images.

An example of contrast settings that worked well to show the moons is:

Min/Max: 304/1286

Log scaling: No.

7.4. Moon #1: Moving away from Jupiter, slowing down and stopping; i.e., turning around.

The distance between images of a moon from hour to hour is a measure of the distance traveled per hour; i.e., the speed. Using Slice I got changes each hour of 17, 12, 10, 5, and –5 pixels. Since speed is a scalor quantity, the average speed is 49/5 or 10 pixels/hr. The average speed before turning around is 44/4 or 11 pixels/hr.

Moon #2: Moving away from Jupiter at a steady speed and in the middle of its orbit, having just emerged from either in front of or behind Jupiter.

Using Slice we got changes of distance of 18, 18, 18, 18, and 18 pixels. The average speed is 18 pixels/hr.

Moon #3: Moving away from Jupiter at a fairly steady speed also.

Using Slice we got changes of pixel distance of 21, 21, 20, 19, and 18 pixels. The average speed is 20 pixels/hr.

Moon #4: Moving toward Jupiter at a steady speed, indicating that its turning point is further out.

Using Slice we got changes of pixel distance of 13, 13, 13, 14, and 14 pixels. The average speed is 13 pixels/hr.

7.5. How I explain the apparent paradox.

In an edge-on view, when a moon is near its turning point most of its motion is away from or toward us. As a moon gets closer to Jupiter more and more of its motion is from left to right or right to left.

IV: Interpreting Your Data.

A potentially frustrating part of this unit is that six hours is not enough information to positively identify each of the four moons. Making an estimate based upon insufficient data, however, is often the best an astronomer can do. In this set of images, Moon #1 turns from moving away to moving toward Jupiter at a place that seems inside positions the other moons are either already beyond or, based on their speed, will go beyond. Moon #4 comes in from far out, further than it seems any of the other moons can reach. This makes these two moons pretty definitely Io and Callisto, respectively.

Using the data from the table, it is still unclear which is which. The activity sheet mentions the relationship between orbit radius and speed. This would seem to be a way to sort them out , but the speed data is inconclusive on this. Theoretically the moon in the larger orbit moves at a slower speed. Using data from a reference book: the ratio of their periods = 2.1 to 1, and the ratio of their circumferences = 1.6 to 1.

This means the outer moon takes 2.1 times as long to go only 1.6 times the distance covered by the closer moon. To do this the outer moon must move more slowly. With more images in the sequence, the data would be more likely to support this expected relationship.

The following "Notes on the Students" is taken from a paper for a conference in Davis, CA in April, 1995, written by Jeff Friedman, Rick Lohman and Mathew McHugh.

"Students had various problems with shifting the images. Some students had difficulty with the notion of a reference point. That is, students didn't realize that the center of Jupiter could be used as a reference point for shifting the images so that they would all line up. Students needed to understand that the important thing is the position of the moons with respect to Jupiter. In some cases, students were concerned that they were 'changing the data' by shifting, even though they were not changing the critical relationship....

"Secondly, students made arithmetic errors and so when they added all the images up, the moons didn't appear to be moving in straight lines. When they learned that the moons should line up (either by noticing the results from another group or because a teacher pointed this out), they were faced with the problem of determining which of the images was improperly shifted. This seems to be characteristic of the sort of problem solving required in our image processing based activities. Students learned that they needed to keep careful records of how they manipulated the images and they devised a variety of methods for identifying the misaligned image.

"After successfully superimposing images, students experienced problems in interpretation. Some students assumed that they were viewing the orbital planes from the top, not the side.

"Many students were not interpreting the image as a projection, but were attending to unreliable indicators of distance. For example, some students reasoned that if a moon appeared fuzzier or smaller or if the distance between the moons in successive hours was becoming smaller then that moon was moving further away from the earth.

"From time to time, we would ask students questions to help us understand their thinking and to encourage them to think more meaningfully about the images."

V. The Mass of Jupiter

This unit was written by HOU teacher Hughes Pack from Northfield-Mt. Hermon School in Northfield, MA. Be sure students are clear that the Jupiter images are an edge-on view of circular orbits. It is because the moons are viewed edge-on that the plot of distance versus time is a sine curve. Refer to Sky and Telescope or Astronomy magazines for monthly plots of the moons' orbits as well as other information pertaining to Jupiter and its moons.

This activity is intended to allow students to learn one method of calculating the mass of Jupiter. Scientists studying distant orbital systems use this same method. Students' success will depend on their preparation and your interaction with them.

7.16. Practice Problem : Be careful about units, such as converting distance to meters and time to seconds. I got $6.02(10)^{24}$ kg, using a hand calculator, which is within 1% of the accepted value, $5.98(10)^{24}$ kg.

7.17. Using Axes or the cursor to find distances from the center of Jupiter will require using the Pythagorean Theorem with the values for the change in x and y. Slice gives a more direct graphic measure of these distances.

7.18. If students do the plot by hand, be sure they plot the moons on the correct side of the line that represents the center of Jupiter. If this graph is done on a graphics calculator or computer, it will be important to use (+) or (-) for distances depending upon whether the moon is to the right or left of Jupiter..

7.19. There is no one way to answer this. The graph shows the change of distance of each of the moons from the center of Jupiter over time.

7.20. The distance is approximately 200 pixels.

7.21. 200 pixels are equivalent to $6.1(10)^{-4}$ radians.

7.22. A derivation of the equation the students use here is on the next page.

D = [$6.63(10)^8$ km] x [$6.1(10)^{-4}$ radians] = 4.0×10^5 km

The actual radius is about 4.22×10^5 km.

7.23. My value from the graph for the time for 1/4 period comes out to be about 9.5 hours.

Multiplying this by 4 gives a period of 38 hours.

9. An estimate of the error will depend on the values each person gets. The point is to think about each place errors could occur and come up with an estimate. The actual period is 42 hours. I felt that my estimate for 1/4 of the period could have been between 8 and 11 hours depending upon how I drew my curve on the graph and when I estimated the turn-around to occur.

200 pixels x [0.63"/1 pixel] x [1 arcminute/60"] x 1 degree/60' x [1 radian/57.3°] = $6.1(10)^{-4}$ radians

10. From the data here, you will get a mass of about 2.0×10^{27} kg.
11. Accepted value : 1.9×10^{27} kg

    % difference : about 7%

Deriving the Equation for the Mass of Jupiter

Recall Kepler's 3rd Law:

(1) $T^2 = k\, d^3$,

where

T is the planet's period of revolution around the Sun,

d is its average distance from the Sun, and

k is the proportionality constant,

which needs to be determined for each orbital system of objects. Our solar system of planets orbiting the sun has its own value of k and Jupiter with its moons has a different value of k.

When Newton realized that the gravitational force provides the centripetal force that makes celestial objects orbit each other, he could then equate the gravitational force law (3) with the centripetal force expression (1) to get the following:

(2) $G\, M_J\, m_m/d^2 = m_m\, v^2 d$

This equation reduces to :

(3) $G\, M_J/d = v^2$

We now have the mass of Jupiter in our equation, so we are getting somewhere. If we could determine d and v, we would be able to get a value for the mass of Jupiter.

The velocity v is simply the orbit circumference (2πd) dvided by the period:

(4) $v = 2\pi d/T$

Substituting it into equation (3):

(5) $G\, M_J/d = 4\, \pi^2\, d^2/T^2$

We can now solve this for the mass of Jupiter to get :

(6) $M_J = 4\, \pi^2\, d^3/GT^2$

The information we need to extract from our images to get the mass of Jupiter is the radius of a particular moon's orbit, d, and the orbital period of the moon, T.

Chapter 8

8. Search for Habitable Planets

Pages76-79

The planet HD209458b produces a maximum drop in brightness of 1.7% during its 3 hour transit. Such drops in brightness repeat every 3.52 days.

Modeling a Transit

See if you can create a model transit with a light bulb as a star in the middle of the room and a small bead or ball as a planet. Have someone make the planet orbit the star, and other observers try different observing positions that would allow them to see the planet transit the star.

The star must be visible during the transit. The Earth is rotating and is traveling in its orbit around the Sun. For an Earth based observation we may only view the stars at night and which stars are visible changes as we go around the Sun.

STARE (STellar Astrophysics & Research on Exoplanets) website - http://www.hao.ucar.edu/research/stare/stare.html - has great info and a planet transit animation on http://www.hao.ucar.edu/research/stare/overview.html

Also a movie EB.mpg at

http://cfa-www.harvard.edu/~jhartman/

Find size of a star

SDSS page on Calculating the radius of a star - http://cas.sdss.org/dr6/en/proj/advanced/hr/radius1.asp

R/Rs = (Ts/T)2(L/Ls)1/2

Relationship of b-v magnitude and temperature is in chart.

Absolute magnitude is

M = m - 5 log d + 5 = -1.44 - 5 log (2.63) + 5 = 1.46

Use Hipparchos skyplot, to find parallax, distance to star, and compute absolute magnitude. http://www.rssd.esa.int/SA-general/Projects/Hipparcos/skyplot.html

8.8 If you do not have data for a full transit, is there any way you could still determine the transit duration?

[You may measure the time from the start of the transit to the greatest dip in brightness and then double that amount.]

8.10 Would the duration be the same for all transits of a given star-planet combination?

[The Duration must be the same for all transits of a given star-planet combination. If it is not constant then there is a chance that we are not observing an actual planet transit. For our research purposes we will use this data to check against other light curves of HD209458b.]

8.16 [extension nuances of K…if it's not mass of Sun, it's (G/4p)ms]

For sunlike K is nearly 1.

Where T is Period, R is orbital Radius and K is 1 AU3/year2

Use this equation to find the orbital radius between the star and planet.

ORBITAL RADIUS

AU*

* AU = Astronomical Unit = average distance from Earth to the Sun

8.18 The students answers whould account for these factors: Is the planet large enough to hold an atmosphere?

What was the result for ACTIVITY III: Finding the Size of the Planet from the Transit Depth?

Does this size allow for an atmosphere? Why or why not?

Have students research the NASA Kepler mission website and report the results of what they find. http://kepler.nasa.gov

Photocopy master on next page.

Date: _______________ Name:

Answer Sheet

Exoplanet Transits

I: Plotting a Transit Light Curve

Image	Time from 1st Observation (minutes)	Counts of HD209458	Counts of Reference Star	Brightness Ratio

Brightness Ratio graph: Enter data from the appropriate two columns in the above table into a spreadsheet and use the graphing function to create a graph.

Chapter 9

9. Formation of the Universe

Pages 80-83

Investigation

Stretching Infinity

Part A: Mathematical Points & Lines

1. Ask your students if they have ever heard the notion that our universe is expanding. Ask them what they think that means. Explain that to help understand how the universe is expanding, they need to visualize points, lines, surfaces, and space.
2. Draw a dot on the chalkboard. Explain that in mathematics, a true point is so small that it has no size. A true point cannot be drawn because it would be too small to be seen. It is just a location. It has "no dimension." It's "zero-dimensional."
3. Ask,What is a line? Ask the students to imagine two points starting out together and then moving rapidly in exactly opposite directions. What do you call the path that these points have traced? [A line.] In mathematics, a line has no thickness (sort of like a point), but extends indefinitely in opposite directions. We say that a line has one dimension. It is "one-dimensional."

Part B: What Is Infinity Times Two?

1. Draw a lines and label evenly spaced points along the line—essentially a number line. Have students imagine the line stretching infinitely in both directions. There are an infinite number of points on the line in between each pair of points. No matter how small a line segment you choose, there are an infinite number of points on each line segment. That is because mathematical points have no size! You can fit gobs of them on any length of line segment.
2. Ask the students to imagine making each pair of points on the line twice as far apart. That includes all the unlabeled points also. Draw another line with labeled points that are separated twice as far apart as on the first line. There are still an infinite number of points between each pair of labeled points.Ask, How many labeled points fit on the segment of the second line that is on your page? [13, including 0.]

Ask, Is the second line longer than the first line? [Twice as long?; no.]

Ask,How long is the first line, including all the points that don't fit on the page? [Infinitely long.]

Ask, How long is the second line, including all the points that don't fit on the page? [Infinitely long.] Explain that if you multiply infinity by two, you still get infinity.

Part C: Space

1. Two lines starting out together and then moving rapidly in opposite directions form a plane—a flat surface that has no thickness, but extends infinitely. A surface is the next dimension higher than a line, with two dimensions. It is "two-dimensional."
2. Two surfaces starting out together and then moving in opposite directions sweep through space—3 dimensions. Space extends infinitely in all directions. Like the example of the line, if space stretches so that every point is twice as far from each other as they were to begin with, has all of space gotten bigger?

9.1. If a star is coming towards us, will its spectrum lines shift towards the red end or the violet end of the spectrum? [The violet end. If necessary, ask them to recall from the acoustic Doppler effect whether the frequency shifted higher or lower when the sound source was coming towards them. You wrote the results on the chalkboard at the end of Part B.]

9.5. How distant is a galaxy that is found to be receding from us at 120,000 km/sec? [About 4 billion LY.]

Investigation

A Ballooning Universe

Students can make two dimensional model universes that expand.

Materials

- Balloon (1/pair of students)
- Marking Pen (1/pair of students)
- Tape Measure (1/pair of students) or a "Do-It-Yourself Tape Measure" (master on p. 48), scissors, and tape for each pair of students

In Class

1. Imagine a universe of many galaxies distributed throughout space. We can make a two-dimensional model of that universe by drawing galaxies on the surface of a balloon.
2. Draw galaxies (dots or blobs) on the balloon. Label each galaxy so it can be identified.
3. With tape measure the distance between a few galaxy pairs. Record the distances
4. Blow up the balloon so that it just barely starts to inflate, then hold the neck of the balloon pinched between two fingers so that it does not lose air. A partner measures the separations between the pairs of galaxies and records the separations the galaxy names and distances in the Distance Table.
6. Predict what the distances between the galaxies will be if you expand the balloon universe to twice the size that it was for the first measurement. Thgen check to see of prediction is correct.
8. Are all the galaxies moving away from one another? [Yes.]

Is there any "center" on the surface of the balloon? [No. The center inside the balloon doesn't count because two-dimensional people living on the two-dimensional surface would not be able to go to that center.]

What are the weaknesses in our model of the universe?

In what ways might our balloon universe model be different from the real universe?

In the real universe, evidence shows that all galaxies are moving away from each other.

Will our universe expand forever or will it stop expanding and start collapsing someday? [No one knows. Scientists today are carefully measuring the rate of expansion, and may soon be able to determine what the fate of the universe will be.]

Frequency and Wavelength

If your students need experience with the concept of waves to grasp the concepts of wavelength and frequency, use a long snaky spring. Have an assistant hold one end. Move the other end sharply up and down once to create a single spring wave that travels down the spring and bounces off the assistant's hand. Explain that we can imagine the spring to represent air molecules (or air pressure, if you wish to be more exact). Sound waves travel through the air very much as the spring wave travels down the spring, but sound waves travel much faster — about 1/3 km/sec

Have the students count how many times your hand moves up and down in ten seconds, as you continue making a single standing wave. Divide by 10 to get the frequency. Explain that for any wave, the number of vibrations per second is called the "frequency" of the wave. The unit of frequency is "cycles/sec" also known as "hertz." .

Now create a standing wave that has two full wavelengths on the spring (two pairs of crests moving alternately up and down). Have the students time it as before, counting how many times your hand goes up and down in 10 seconds. Have them record the frequency and wavelength

If you can move your hand fast enough, make a standing wave with three full wavelengths on the spring and have your students find its frequency as before.

Ask, What is the relationship between a wave's frequency and its wavelength? [Higher frequencies correspond to shorter wavelengths.]

Bibliography for A Changing Cosmos

This listing contains references that were used in writing the Student Guide and Teacher's Guide for *Changing Cosmos*.

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The HOU pilot teachers of the high school project include:
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Teacher Resource Agents, TRAs, are major contributors to the on-going operation and development of HOU. They run teacher workshops, provide on-going feedback, and are developers of new HOU materials and procedures. Some of these TRAs were part of the group of pilot teachers. (See the Teacher Reference Manual for a list of the pilot teachers.) TRAs include the following:
Art Griffin, Pam Bowers, John Kolena, Rich Lohman, Ralph Mazzio, Kate Meredith, Kevin McCarron, Tom Morin, Sharon Carr, Sheron Snyder, Marilyn Zimny, Glenn Reagan, Tinka Ross, Tim Spuck, Hughes Pack, Dane Toler and Bill Rodriguez.