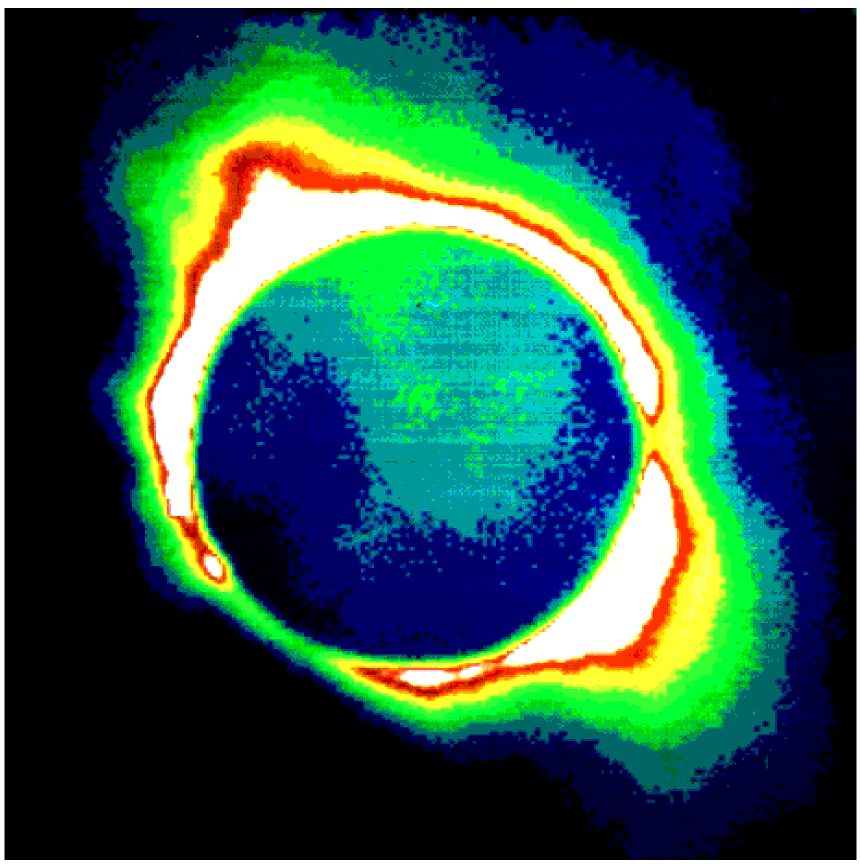
HANDS-ON UNIVERSE™

HIGH SCHOOL SCIENCE AND MATH
IN THE CONTEXT OF ASTRONOMY
INVESTIGATIONS

Teacher Book



by Lawrence Hall of Science
University of California, Berkeley
Lawrence Berkeley National Laboratory
and TERC of Cambridge, Massachusetts

TERC

LHS

Lawrence Hall of Science
University of California, Berkeley

HOU provides a visual and analytic way of exploring the universe.

Use HOU images from professional telescopes, along with HOU image processing software, to pursue investigations of astronomical objects, phenomena, and concepts. Opportunities available to HOU students can lead to accessing professional-grade telescopes via the World-Wide Web for observations as part of research projects such as searching for supernovae and asteroids.

- HOU has been developed and operated by staff at Lawrence Berkeley National Laboratory and Space Science Laboratories at the University of California at Berkeley, Californa, with generous support from the National Science Foundation (grant # ESI-9252915) and the US Department of Energy. The HOU curriculum was developed by TERC with contributions from the Berkeley staff and teachers. The educational center for HOU currently resides at Lawrence Hall of Science, University of California, Berkeley.

- The Berkeley staff responsible for the development of the HOU system includes:
  Carl Pennypacker, Elizabeth Arsem, Kinshuk Govil, John Refling, Gerard Monsen, Jeff Friedman, Dick Treffers, Julia Lee, and Mimi Kwan (with past contributions from Silvia Gabi, Bruce Grossan, Michael Richmond, and Rori Abernathy).

- The curriculum development team includes:
  Tim Barclay and Jodi Asbell-Clarke from TERC
  (with contributions from Hughes Pack, Northfield-Mount Hermon School; Phil Dauber, Alameda High School; Rich Lohman, Albany High School; Tim Spuck, Oil City High School; Vivian Hoette, Adler Planetarium; Alan Gould, Lawrence Hall of Science; Geri Monsen, and Carl Pennypacker).

- Lawrence Hall of Science HOU staff includes:
  Carl Pennypacker, Alan Gould, Miho Rahm, Lulu Lin, and Amelia Marshall.

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Teacher Book

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Acknowledgments

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The HOU pilot teachers of the high school project include:

Jaime Akin, Martha Bright, Carlon Ami, Pablo Canto, Gloria Cooper, Curtis Craig, Phil Dauber, Dan Gray, Jana Gray, Blaine Greenhaulgh, Carole Helper, Vivian Hoette, Linda Howell, Carey Inouye, Onyema Isigwe, John Kolena, John Koser, John Kounas, Harold Lefcourt, Jeff Lockwood, Rich Lohman, Dave Mallinder, Larry Mascotti, Peter Michaud, Paul Moreau, Tom Morin, Christer Nilsson, Hughes Pack, David Parisian, William Pisciella, Riitta Raty, Bob Riddle, Bill Rodriguez, Mike Rosenfeld, Jose Salinas, Abbie Schirmer, Mary Schrader, Joan Schwebel, Frank Sheldon, Tom Sherow, Tim Spuck, Dane Toler, and Maisha Washington

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.

Forward

HOU provides students with a visual and analytic way of exploring the universe. Using images from professional telescopes along with image processing software developed for use in the classroom, students pursue guided investigations of astronomical objects and phenomena. HOU blends content learning with critical thinking skills and processes such as data interpretation, measurement techniques, and using appropriate tools for exploration. The opportunities available to HOU students range from using a well-tested and engaging curriculum program to accessing telescopes for their own observations to doing authentic research such as searching for supernovae and asteroids

The HOU curriculum was originally developed and piloted under a National Science Foundation grant, with new units added each year and changes made in response to feedback from the pilot teachers. This year 2000 version of the HOU Teacher Reference Manual includes corrections and edits to the 1997 version based upon a thorough review of the book and upon feedback from Teacher Resource Agents (TRAs) and teachers.

Welcome to Hands-On Universe™

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 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 the 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, and what is 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

Bringing Astronomical Explorations to the Classroom

For the past seven years, with support from the National Science Foundation, the Department of Defense, and the Department of Energy, Hands-On Universe™ (HOU) has developed and field tested an educational program that enables high school students to request their own images from professional telescopes. HOU students download CCD images to their classroom computers and use HOU's powerful image processing software to visualize and analyze their data. This is supported by a comprehensive curriculum that integrates into astronomical investigations many of the topics and skills outlined in the national goals for science and mathematics education. HOU is also developing activities and tools for use in informal science education, and units for use at the middle school level.

The HOU Telescopes: Originally student image requests were all handled by the 30-inch automated telescope of the U.C. Berkeley astronomy department at Leuschner Observatory. A growing network of telescopes is now being brought on line, including at least one in the Southern Hemisphere, that will be used to meet the increased demand as well as routing requests to the best telescope, based on weather, geography, scheduling and equipment.

The HOU Telecommunications: HOU Web pages are the primary interface between HOU students and the telescope image request and retrieval system.

The HOU Image Processing Software: The image processing software runs under Windows on a 486 (or extended 386) as well as a Macintosh II series or better. Image processing tools include: min/max adjustment for contrast, log scaling, zoom, a variety of color palettes, and image manipulations such as rotations, flip, shift, and the arithmetic functions of add, subtract, multiply and divide. For data analysis, brightness Counts are displayed for each pixel and slice plots and histograms show brightness distributions. Photometry routines calculate full width half max and sky-subtracted brightness.

The HOU Curriculum: The curriculum units integrate mathematics, science and technology in the context of exciting astronomical explorations. HOU addresses many of the goals set by the National Council of Teachers of Mathematics and the National

Research Council for math and science education. Through the investigation of the solar system, galaxies, variable stars, and supernovae, students develop problem-solving techniques and critical thinking skills. Along the way students discover a need for algebra, geometry, various data representations and interpretations, as well as physical principles such as force and motion, energy transformations, and properties of light. The classroom computer, the image processing software and telecommunications are regarded as research tools that enable students to pursue their investigations.

The HOU Teacher Training and Support Teacher Resource Agents (TRAs) hold teacher workshops and provide on-going support for new teachers in their region. We anticipate that this will lead to exponential growth in the use of HOU. The HOU WWW pages provide a forum for communication among teachers, students, HOU staff and professional astronomers. The later, through email and classroom visits where possible, act as mentors for teachers and students in their HOU investigations. The TRA method of expansion is designed to encourage regional growth since TRAs generally train teachers within their own geographical areas.

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.

For More Information on HOU:

Go to the HOU Home Page on the World Wide Web: http://hou.lbl.gov
send email: houstaff@hou.lbl.gov
or write: Hands-On Universe™ , University of Californa,
Lawrence Hall of Science, Berkeley, CA 94720

REVIEW OF THE CURRICULUM

The HOU curriculum continues to be upgraded, incorporating suggestions from TRAs and teachers. The following set of materials should completely replace earlier versions of the HOU curriculum.

The HOU curriculum is divided into Themes based on astronomical techniques. Each Theme is available as a separate booklet. The Themes are:

I. Introduction to Image Processing
II. Finding Features
III. Supernova Search
IV. Measuring Size
V. Measuring Brightness
VI. Measuring Distance
VII. Measuring Color

Within each Theme there are Discussion Sheets, Curriculum Units and Supplementary Activities. See the end of this Review for a listing of these pieces within each Theme. In general, the Discussion Sheets provide explanations of new concepts and equations. The Units introduce the basic techniques for using the HOU software and images and include investigations and challenges. The Supplementary Activities include enhancement, enrichment, and alternative activities. Some are for review of background concepts or to introduce advanced concepts that are related to but not covered in the units. Many of the Supplementary Activities are off-computer. See the Suggested Sequences for Integrating HOU into Your Courses at the end of this manual.

Teacher Theme Notes are provided with each Theme. Various activities are suggested for follow-up and assessment of the skills learned within the activity sets of a Theme. Some assessment exercises apply specifically to units or activities within the Theme, but others examine a more overall understanding of the Theme itself. Along with the suggested assessment activities is a checklist of skills and concepts to assist you in evaluating HOU students. Student outcomes described by the national standards for math and science education are provided to help you integrate the HOU curriculum into other projects and studies that relate to these goals.

Image lists and material lists are included to assist in preparation for using HOU in your class. The images for each of the curriculum books are included with HOU-IP when you install the software from the CD. These images are in folders for each of the units. The number preceding each folder identifies the Student Book in the series of books. You are urged to make sure the HOU computer is ready to go before your class begins, much as you would do in any other laboratory course.

The HOU curriculum is intended to encourage curiosity and exploration. As in much of astronomy, there are not always "right" and "wrong" answers and the process of discovery is most important. Throughout the entire curriculum, we hope you will support an environment of inquiry and investigation, revealing the scientist within each and every student.

Sequences of Activities Within Each Theme

[SA = Supplementary Activity]

Introduction to Image Processing
Teacher Theme Notes
Introduction to Image Processing Unit
CCD Images - A Color Coding Activity (SA 1)
Teacher Notes with answers to questions in the Units and selected Supplementary Activities

Finding Features
Teacher Theme Notes
Messier Catalog
Constants Sheet
Browser's Guide to the Universe Unit
Moon Match Unit
Galaxy Features Unit
Teacher Notes with answers to questions in the Units and selected Supplementary Activities

Searching for Supernovae
Teacher Theme Notes
Discussion Sheet: Searching for Supernovae
Techniques for Finding a Supernova Unit
The Image Manipulation Challenge (SA 2)
Discover a Supernova Unit
Teacher Notes with answers to questions in the Units and selected Supplementary Activities

Measuring Size
Teacher Theme Notes
Constants Sheet
Jupiter Crash Unit
Comparing Lunar Crater Heights Unit
Investigating Moon Craters Unit
Tracking Jupiter's Moons Unit
Simulating Orbits (SA 3
Using Large and Small Numbers (SA 4)
Explanation of a Light Year (SA 5)
Using Angles to Measure Sizes (SA6)
Measuring Your Computer Screen (SA 7)
Discussion Sheet: Measuring Size with Images
Measuring Size with Images Unit
Measuring the Size of Moon Features Unit
The Mass of Jupiter Unit
Planets Around a Pulsar (SA 8)
Teacher Notes with answers to questions in the Units and selected Supplementary Activities

Measuring Brightness
Teacher Theme Notes
Constants Sheet
Brightness Conversion Table
Discussion Sheet: Photometry Techniques
The Effect of Observing Conditions (SA 9)
Demonstrating Observing Conditions (SA 10)
An Example of Calibration (SA 11)
Photometry Techniques Unit
Discussion Sheet: Supernova Light Curves
Supernovae Light Curves Unit
Discussion Sheet: Science of a Supernova
Discussion Sheet: The Magnitude Scale
Some Exponential Games (SA 12)
Magnitude Calculations (SA 13)
Comparing the Magnitudes of Stars (SA 14)
Absolute Magnitude (SA 15)
Tools for Measuring Brightness: Auto Aperture and Aperture (SA 16)
Measuring the FWHM of a Star (SA 17)
Teacher Notes with answers to questions in the Units and selected Supplementary Activities

Measuring Distance
Teacher Theme Notes
Constants Sheet
Brightness Conversion Table
Discussion Sheet: The Cosmological Distance Ladder
Techniques for Measuring Distance (SA 18)
Using a Light Bulb to See How Brightness Varies with Distance (SA 19)
Measuring Spherical Distributions (SA 20)
A Thought Experiment for Brightness and Distance (SA 21)
Determining Distance or Luminosity Using Apparent Brightness Unit
Discussion Sheet: Cepheid Variable Stars as Distance Indicators
Cepheid Variable Stars Unit
Examining Periodicity (SA 22)
Demonstrating Gas Laws (SA 23)
Discussion Sheet: The Science of a Cepheid Variable Star
Teacher Notes with answers to questions in the Units and selected Supplementary Activities

Measuring Color
Teacher Theme Notes
Constants Sheet
Brightness Conversion Table
Hertzsprung-Russell Diagram
Discussion Sheet: Measuring the Color of Stars
Observing Colors (SA 24)
Observing Color and Temperature (SA 25)
Measuring the Color of Stars with Images Unit
Discussion Sheet: The HR Diagram
Classification and Plotting (SA 26)

Introduction to Image Processing

Teacher Theme Notes

The goal of this Theme is to teach enough beginning skills using the software so students can start doing astronomy investigations using the image processor as a marvelous tool. The initial activities are written with step by step instructions. These need to be used intelligently as an aid for gaining familiarity with the software. Just filling in the blanks in order to complete the 'exercise' does not tend to make one a proficient user of the image processor. Activity IV, Explore a Solar Eclipse, asks students to apply what they have learned using a new image, and it provides a way to check their understanding. Careful step by step instructions are not given here. If students have trouble, they should refer to the *Introduction To Image Processing Unit*, not you.

Features of the image processing software and tools introduced in this book are:
Menu Bar, Display Controls Bar, Tools Bar, and Status Bar
Min/Max, Log, Zoom and **Redraw**, on the Display Controls Bar.
Open, Palette, Cleanup, Auto-Aperture, and **Print** on the Tool Bar.
Slice and **Zoom Box** on the Tool menu.

More image processing tools introduced in the Searching for Supernovae Book are:
Shift, Subtract, and Multiply in the Manipulation menu.
Sky, Axes and Find on the Tool Bar.

This book uses the moon image and the solar eclipse image, which are just two examples of the kinds of images available. Refer to the *Browser's Guide to the Universe Unit* in the Finding Features Book for ideas about exploring other images. Another unit that introduces using the image processing software is *Jupiter Crash* in the Measuring Size Book.

Student Outcomes for Introduction to Image Processing

Upon completion of this Theme students should exhibit competence in the following skills and concepts taken from the national goals and standards for math and science education:

1. Alternate data representations, from pixels on an image to plotted data.
2. Graph interpretation.
3. Measurement of sizes using cursor readings or a Slice graph.
4. Comparison of sizes using ratios.
5. Familiarity with objects in our solar system.
6. Familiarity with logarithmic scaling.
7. Systematic use of technology to enhance image features for classification purposes.

Suggested Checklist for Assessment for Introduction to Image Processing:

While a student is using the image processing software with a CCD image, the following concepts and skills may be evaluated:

1. Understanding of **Min/Max** and the **Log** Scaling.
2, Using image processing tools to see image features that were not visible in the original image display.
3. Using the cursor and **Slice** to measure the size of objects in pixels.

Follow-Up and Assessment Activities for Introduction to Image Processing

1. Choose a new image of any object and display it using an alternate color palette (not the default). Select **Log Scaling** and/or adjust the **Min/Max** to enhance features that are not visible on the original display.
2. Measure the size of an object within an image in pixels and develop a technique for determining the actual size of the object in meters.

Image List for Introduction to Image Processing

Introduction to Image Processing Unit	*moon* *eclipse1*
Suggested images for follow-up activities	*crab* (the crab nebula, a supernova remnant; from the Measuring Size with Images Unit set in the Measuring Size Book) any of the *galaxy* and *browser* images from the Finding Features Book.

Materials List for Introduction to Image Processing

none

Unit by Unit Teacher Notes for Introduction to Image Processing

A set of images titled “Welcome to the Universe” is included on the HOU 2000 CD. These images go from our solar system to the Milky Way galaxy and beyond. Showing them as an introduction to Hands-On Universe gives an overall sense of what is to come.

A file titled “Tool Box” on the HOU 2000 CD is a Help file that especially applies to the first books. This Help file is done with excellent graphics. The Tool Box file also has an option called xyz that provides further Help.

More images are on the CD under "Launch Explorations." In addition to these images there is a file called ToolBox that is a Help file done with excellent graphics. Another option at the ToolBox file is "HOU Image Processing Help". This provides further help in text format."

Introduction to Image Processing Unit

Activity I: Displaying an Image

2-6. Min/Max. Since the 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

Activity II: About the Display

14. 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.

15. 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.

16. 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.

17. 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.

18. 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. (See 2-6. Min/Max on the previous page for an explanation of the linear scale.)

Activity III: Tools For Analyzing Images

20. The different high points 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.

21. The distance from peak to rim is 32 to 36 pixels depending upon the direction of the slice and deciding where the crater edge begins.

Activity IV: Explore a Solar Eclipse

The answers in this activity depend upon measuring screen distances by either:

cursor readings on the Slice line in the image, or
distance readings on the **Slice Graph**.

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

24. 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.

25. About 5 Earths would fit between the rim and the top of the prominence.

27. 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.

Introduction to Image Processing
Supplementary Activity 1:
CCD Images - A Color Coding Activity

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.

Finding Features

Teacher Theme Notes

This Theme is intended for classes that wish to proceed with image processing skills following the *Introduction to Image Processing Unit*. Very little background in math is required for these activities beyond ratios. The units have been found to be stimulating for all grade levels.

The *Browser's Guide to the Universe Unit* 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 *Moon Match Unit* 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. Finally, in the *Galaxy Features Unit* students need to do image processing to answer scientific questions about galaxy classification. Each of these units exposes new astronomical objects and phenomena while teaching the technological skills necessary to study them. One goal is for each student to ask "What is that object or feature ?" and choose to explore more about it.

Student Outcomes for Finding Features Book:

Upon completion of this Theme students should exhibit competence in the following skills and concepts taken from the national goals and standards for math and science education:

1. Interpretation of pixels on an image and in plotted data, and transformation from one to the other.
2. Ability to classify objects and identify trends and patterns within a data set.
3. Systematic use of technology to enhance image features for classification purposes.
4. Familiarity with lunar surface features, galaxy types, and the range of objects in the universe.

Suggested Checklist for Assessment for Finding Features Book

While a student is using image processing techniques to find features on a CCD image the following concepts and skills may be evaluated:

1. Was **Log** scaling and different color palettes used in an effort to enhance features on an image?
2. Were **Min/Max** values adjusted in a logical fashion?
3. Were procedures recorded for future use by themselves or others?

4. Were features identified that did not appear on the image when it was first opened?

Follow-Up and Assessment Activities for Finding Features Book

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.

Image List for Finding Features Book

Browser's Guide to the Universe Unit	*browser1* through *7*
Moon Match Unit	*moon*
Galaxy Features Unit	*galaxy1* through *8*

Materials List for Finding Features Book

none

Unit by Unit Teacher Notes for Finding Features

Browser's Guide to the Universe Unit

The intent of this unit 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.

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.

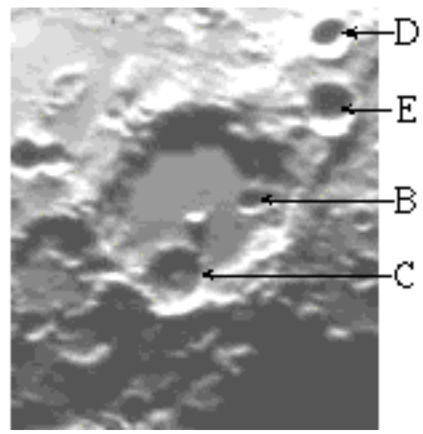
Finding Features Filenames (with descriptions)

browser1 (a.k.a. *moon*)— lunar surface with craters
browser2 (a.k.a. *jup1*)— Jupiter
browser3 (a.k.a. *eclipse1*) — Sun and moon during a total eclipse
browser4 (a.k.a. *m57*) — planetary nebula
browser5 (a.k.a. *galaxy1*) — a face-on spiral galaxy
browser6 (a.k.a. *galaxy5*) — a peculiar galaxy
browser7 (a.k.a. *crab*) — supernova remnant

Finding Features Book
Moon Match Unit

Matching means approximating; it does not make sense to try for or expect exact duplication. There is no separate answer sheet for this unit.

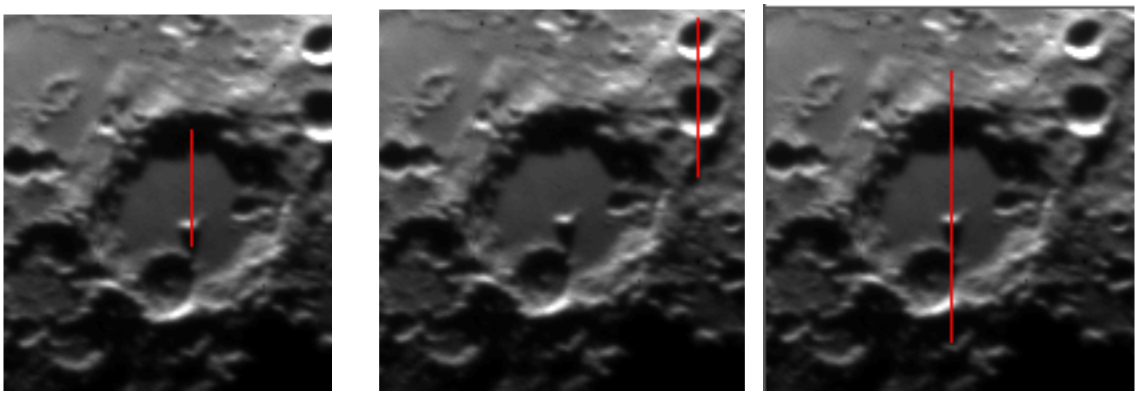
A wide range of Min/Max values can produce similar appearing images, especially when comparing with Xeroxed copies, which are typically darker than the original. The answers provided below refer to the craters labeled in the following image. Albategnius is the largest crater in the image. The size of the individual pixels is the clue about Zoom.



1. This is simply a Zoom 2 version of the image.
2. This is a Zoom box image with Zoom 4, inside Albategnius, of the peak and Crater C.
3. This is using the IGRAY, inverse grey, color palette and Zoom 2.
4. This is another Zoom box, this time of Crater E, with Zoom 8.

Activity II: Match the Slice
The slices have proved harder to match than the images. All the slices are vertical ones. Values along the x-axis indicate distances along the slice. Using the **Status Bar,** students can check where similar configurations occur.

5. 6. 7.



Answer Sheet

Galaxy Features Unit

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

Name (see Galaxy Atlas): ______ *M100*

Features used to identify galaxy: ______________

____

Galaxy Type:_______ Spiral

Spiral Arms ☒ Bar ☐ Ring ☐

Dust Lane ☐ HII Regions ☒

Companion Galaxy ☐ Foreground Stars ☒

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

Name (see Galaxy Atlas): ______M82

Features used to identify galaxy: ______________

____

Galaxy Type: _________Peculiar

Spiral Arms ☐ Bar ☐ Ring ☐

Dust Lane ☒ HII Regions ☒

Companion Galaxy ☐ Foreground Stars ☒

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

Name (see Galaxy Atlas): _____M51

Features used to identify galaxy: ______________

____

Galaxy Type:_____ Spiral

Spiral Arms ☒ Bar ☐ Ring ☐

Dust Lane ☐ HII Regions ☒

Companion Galaxy ☒ Foreground Stars ☒

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

Name (see Galaxy Atlas): ___NGC4636

Features used to identify galaxy: _______________

____

Galaxy Type:_______ Elliptical

Spiral Arms ☐ Bar ☐ Ring ☐

Dust Lane ☐ HII Regions ☐

Companion Galaxy ☐ Foreground Stars ☐

Galaxy 5: Display: Min: ___ Max: ___ Log ☐ Rough Sketch:

Name (see Galaxy Atlas): _______M95

Features used to identify galaxy: _______________

____

Galaxy Type: ______ Spiral

Spiral Arms ☑ Bar ☑ Ring ☑

Dust Lane ☐ HII Regions ☐

Companion Galaxy ☐ Foreground Stars ☑

Galaxy 6: Display: Min: ___ Max: ___ Log ☐ Rough Sketch:

Name (see Galaxy Atlas): _____NGC2146

Features used to identify galaxy: _______________

____

Galaxy Type:______ Peculiar___________

Spiral Arms ☐ Bar ☐ Ring ☐

Dust Lane ☑ HII Regions ☐

Companion Galaxy ☐ Foreground Stars ☑

Galaxy 7: Display: Min: ___ Max: ___ Log ☐ Rough Sketch:

Name (see Galaxy Atlas): _____NGC2841

Features used to identify galaxy: _______________

____

Galaxy Type: ______ Spiral

Spiral Arms ☒ Bar ☐ Ring ☐

Dust Lane ☐ HII Regions ☒

Companion Galaxy ☐ Foreground Stars ☒

Galaxy 8: Display: Min: ___ Max: ___ Log ☐ Rough Sketch:

Name (see Galaxy Atlas): _____NGC4697

Features used to identify galaxy: _______________

____

Galaxy Type: ______ Elliptical

Spiral Arms ☐ Bar ☐ Ring ☐

Dust Lane ☐ HII Regions ☐

Companion Galaxy ☐ Foreground Stars ☒

Searching for Supernovae

Teacher Theme Notes

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 Research Project, in which classes adopt a group of galaxies to monitor for supernovae, is now becoming a reality.

This Theme 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 (see Measuring Brightness Book) as well as for other objects in the sky such as comets and asteroids.

Additional image processing tools not introduced in the *Introduction to Image Processing Unit* are:

> **Shift, Subtract,** and **Multiply** in the **Manipulation** menu**.**
> **Sky, Axes** and **Find** in the **Data Tools** menu.

Student Outcomes for Searching for Supernovae

Upon completion of this Theme students should exhibit competence in the following skills and concepts taken from the national goals and standards for math and science education:

1. Classifying objects and identifying trends and patterns within a data set.
2. Systematic use of technology to enhance image features for classification purposes.
3. Familiarity with the phenomenon of supernovae.
4. Questioning our place in the universe.
5. Judgment on strong and weak conclusions to be drawn from collected data.
6. Dealing with complex systems involving multiple factors.

Suggested Checklist for Assessment for Searching for Supernovae

While a student is searching for supernovae on a CCD image, the following concepts and skills may be evaluated:

1. Was the sky brightness subtracted?

2. Were the x and y coordinates of the reference star determined correctly on each image?
3. Was the image shifted correctly in each direction?
4. Was the image normalized correctly?
   A. Was the normalization factor determined correctly?
   B. Was the image multiplied by the normalization factor?
4. Was the image subtraction performed correctly?
5. Was the positive or negative conclusion of the supernova search well justified based on the data?

Follow-Up and Assessment Activities for Searching for Supernovae

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

Image List for Searching for Supernovae:

Techniques for Finding a Supernova Unit	*m51fake1* *m51fake2* *m51fake3* *m51nor*
Supplementary Activity 2	*m51nor*
Discover a Supernova Unit	*snw* *snx* *sny* snz

Materials List for Searching for Supernovae

none

General Comments Related to Student Questions or Problems

1. After completing a search unit, students may not see the forest for the trees. To discover a supernova involves a series of steps each of which tends to be fussy and difficult, at least initially. As a result, students are working to understand the steps and to do them correctly. In the meantime, they may lose a sense of why; i.e., looking for a supernova that is not visibly obvious in the image. Questions to ask: How does each step contribute to finding a supernova? Or, conversely, what if you

did not do a given step, or did it poorly? Always going back to the point of the search.

2. When Shifting, enter offset values to the nearest hundredth of a pixel.

3. Using **Auto Aperture** after aligning the images, the center coordinates of the reference star in the two images often differ - as if the images were not aligned after all. The reason for this discrepancy is because the center listed in **Auto Aperture** is a center of brightness while **Axes** gives the geometric center of the object. These are not necessarily the same. To see that the images really are still aligned, use **Axes** again.

4. The background sky in the Difference image is typically very textured. Why isn't it all uniformly zero brightness? This question is one you might ask students. The background sky is not uniformly one brightness, so the result after subtracting an average Sky value is a scatter of plus and minus remainder brightness values. This pixel by pixel variation, however, will not be the same in both images. As a result subtracting one from the other produces the textured background sky.

To see this scattered nature of the background sky, you can sample pixels using the cursor, noting the Counts listed in the **Status Bar**. Another way is to **Zoom box** on a portion of the background sky and use **Histogram** in the **Data Tools** menu to see the distribution of pixel brightness. The Bell curve of sky pixel Counts shows both the most common sky value, called the mode which is the Count for the peak of the curve, and the spread of values, which is the width of the curve.

5. When you look at the image from the difference file, some features may look as if they have a silver lining, such as spiral arms or a black crescent as if showing phases. Asking students the reason for this is a good question. This occurs if the alignment is still off. If you think of the subtraction as two image transparencies on top of each other, there is under-subtraction where the upper image hangs over causing a silver lining because nothing is subtracted from the overhang and over-subtraction where the under image sticks out causing the black part because the subtraction is just from the sky. This will occur if integer center values, given in **Auto Aperture**, are used instead of the decimal values from **Axes** to compute the offsets.

6. Some students worry that all this shifting and normalizing is changing the data. This is true for the displayed image, but it does not affect the image file data unless you specifically "Save" the changed image. This option occurs upon closing an image window, and you decide to save the image under the same file name.

7. Which images do you manipulate? The choice differs between the Techniques and Discover Units. This difference applies to revised versions of Discover after version 9/96. In Discover each of the images is corrected to fit the reference image, *snx*. This makes the process of aligning and normalizing less cumbersome than choosing only to manipulate the reference image, which means having to realign and renormalize the reference image each time to fit each of the other three images. The argument for

only manipulating a reference image is that any important data showing a new supernova is on the new images and the less you mess with them the better. However, you are not manipulating the original images, which are still on your hard disk as well as on the HOU web site, so the original data are not at risk.

Unit by Unit Teacher Notes for Searching for Supernovae

Techniques for Finding Supernovae Unit

While the *Discover a Supernova Unit* can be thought of as an alternative to using this Techniques Unit, many teachers use both, starting with the Techniques Unit and followed by the Discover Unit. This gives the students more practice with the concepts and processes involved, which teachers have said is important. Using both can still be done in a week plus a day or two. Both units aim to give students familiarity with the processes utilized for finding a supernova. The Techniques unit breaks down the steps involved 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 set of *m51fake* images, all of which are of galaxy M51, called the Whirlpool Galaxy, have a bright 'new star' added, thus their name fake. The *m51nor* image is a normal image of M51.

The order of steps introduced is as follows:

Activity I: Subtracting to reveal a new star that was not seen in the previous, normal image.

Activity II: Aligning the two images so they line up before the subtraction is done.

Activity III: Adjusting for Brightness Differences due to changing observing conditions before subtracting images, subtracting background sky from both images and multiplying the reference image by the Normalization Factor. In this activity, the images are already aligned.

Searching for Supernovae Book
Discover A Supernova Unit

The four images used in this unit are of supernova SN1990H, the eighth supernova discovered in 1990. In this unit students work with all the steps together that are needed for searching, rather than breaking them down into one step per image as The Techniques Unit does.

Activity I: 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.

Activity II: 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 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.

Activity III: 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

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:

Subtract Sky to take out the background sky light.

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/Cw = 28695/23520 = 1.22
Cx/Cy = 28695/19288 = 1.49
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.

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

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 Measuring Brightness Theme section.

Measuring Size

Teacher Theme Notes

This Theme is intended to 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.

Sizes of various features on an image can be compared directly by using the ratio of the number of pixels spanned by each object, as in the *Comparing Lunar Crater Heights Unit*. A similar technique is used to compare the velocities of moving objects in the *Tracking Jupiter's Moons Unit*. 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*.

Image measurements are based on the projected length or width of the object as visible to us on Earth. Since objects are generally at some arbitrary angle with respect to our line of sight, we can not always determine the actual width of an object such as a galaxy. The *Measuring the Size of Moon Features Unit* explains how to use an angle with respect to our line of sight to account for projection effects and to calculate an actual size.

Student Outcomes for Measuring Size

Upon completion of this Theme students should exhibit competence in the following skills and concepts taken from the national goals and standards for Math and Science education:

1. Derivation and application of functions and ratios within the context of a scientific technique.
2. Familiarity with the number scale and scientific notation, and use of appropriate units of measurement.
3. Interpretation and transformations among various data representations beginning with pixels on an image, leading to angular size and then to linear size.

4. Use of ratios to convert from one type of measurement to another.
5. Use of geometry to derive, validate and apply the Small Angle Approximation.
6. Familiarity with and comparison of sizes of features ranging from lunar craters to the diameter of galaxies.

Suggested Checklist for Assessment for Measuring Size

When a student is measuring the size of an object on a CCD image, the following concepts and skills may be evaluated:

1. Measuring the width of the object in pixels.
    - A. Were edges defined carefully and in a logical fashion?
    - B. Was a horizontal or vertical line used, or if not, was the angle of the line accounted for in the length measurement?
    - C. Was the difference in coordinates calculated correctly? (e.g. $x_{final} - x_{initial}$)

2. Calculating the Size (or Distance) of the Object with the Small Angle Approximation.
    - A. Was the size of the angle to be measured checked to see if it was small enough for the Small Angle Approximation to be valid?
    - B. Were radians used for the subtended angle?
    - C. Was the distance (or size) obtained correctly from given reference material?
    - D. Was the size (or distance) calculated in the correct units?

    Diameter (in specified units) = Distance (in same units) x θ (in radians)

    -- or --

    Distance (in specified units) = Diameter (in same units) ÷ θ (in radians)

3. Using Plate Scale to calculate the subtended angle of an object in the sky.
    - A. Was the plate scale obtained correctly from **Image Info** or another reference?
    - B. Was the angle, θ, calculated correctly in arc seconds?

    θ = (width in pixels) x (plate scale in arcsecs/pixel)

Follow-Up and Assessment Activities for Measuring Size

1. Observe the Moon through a telescope or binoculars. Identify the craters you studied on images.

2. 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.

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.

4. Choose an image with an object of known size. Find the size of another object or feature in the image.

5. 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.

6. 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.

Image List for Measuring Size

Jupiter Crash Unit	*jup16* *fireball*
Comparing Lunar Crater Heights Unit	*moon*
Investigating Moon Craters Unit	*moon*
Tracking Jupiter's Moons Unit	*jup5* through *10*
Measuring Size with Images Unit	*moon* *jup1* *eclipse1* *rori* *m51* *crab*
Measuring the Size of Moon Features Unit	*moon*
The Mass of Jupiter Unit	*jup5* through *10*

Materials List for Measuring Size

Supplementary Activity 3 Simulating Orbits

Old fashioned 78” record or other rotating turn table.
A ball to tape to the edge of the turn table.
Graph paper and centimeter rulers.

Supplementary Activity 7: Measuring Your computer Screen

string
protractor
meter stick
chair

Unit by Unit Teacher Notes for Measuring Size

JUPITER CRASH UNIT

This unit incorporates image processing and measurement with physics concepts such as kinetic energy and can lead to a conversation of rich cultural context such as what would happen in the event of a major Earth catastrophe.

1. 511 pixels in the x-direction and 586 pixels in the y-direction.
2. 511 x 586 = 299446
3. The diameter of the fireball is about $1/10^{th}$ the diameter of Jupiter so it is almost the size of Earth.
4. A collision of this magnitude would probably kill a significant fraction of the life on Earth (similar to the extinction of the dinosaurs 64 million years ago) but would not change the Earth's orbit around the Sun.
5. The mass of the comet fragment is equal to its density times its volume. Since the densities of the comet and the Earth are about the same, the ratio of the mass of the fragment to the mass of the Earth is equal to the ratio of their volumes. (The volume of a sphere equals $4/3\ \pi\ r^3$).
6. Momentum is equal to mass times velocity. If the velocity of the Earth is 1/2 the velocity of the comet, and it's mass is 6.4×10^{10} times greater, then the momentum of Earth is 6.4×10^{10} (1/2) = 3.2×10^{10} times greater than the momentum of the comet fragment.
7. The spots are about $1/10^{th}$ the size of the diameter of Jupiter so they are roughly Earth size.
8. Let the students hypothesize on this for a while and then look at a more recent image of Jupiter such as the ones included on the HOU CD in Launch Explorations/Planets/ Jupiter Rotation.

Measuring Size Book
COMPARING LUNAR CRATER HEIGHTS UNIT

In Activity II, using image coordinate readings to measure distances, the instructions are to move vertically. In this way, the distance is simply the difference between the y-coordinate readings. The difference between x-coordinate readings would apply for moving horizontally. When slices are taken along an angle the software approximates the length of the slice, but its accuracy depends on the angle used. A 45° angle or any angle where the ratio of the sides is an integer works quite well.

In Activity III the Slice graph can be confusing. The brightest portions of the image are also Moon features that stick up, so a graph of brightness versus distance can be misinterpreted as being a graph of height or elevation versus distance.

In both Activities II and III it is not clear exactly where the shadows begin and end. One has to make a choice at the beginning; for instance, between the pixel where there is an initial big drop in the brightness versus the pixel that is nearer to the final shadow brightness. These two places typically differ by two pixels, and the corresponding ambiguity applies at the termination of the shadow as well. Thus a shadow could be measured as 12 pixels long or only 8 pixels long, depending upon the criteria chosen. A similar decision needs to be made when looking at the Slice graph. When dragging across the Slice graph, watch the box moving along the Slice line in the image.

There is no right way, but it is important to be consistent in how you decide where the edges are for the shadow in each crater..

Author's Note:
Here is a table of my data.

CRATER DATA				
	SHADOW LENGTH	SHADOW LENGTH	BRIGHTNESS	BRIGHTNESS
CRATER	Cursor (x,y)	Slice (D1 to D2)	Status Bar	Slice Graph
A	(65,121) to (65,102)	7 to 30	6787/5489	17047/6651
B	(90,89) to (90,83)	2 to 11	3960/6240	8762/13072
C	(65,68) to (65,58)	8 to 19	7339/3414	9757/3414
D	(118,153) to (118,144)	1 to 13	11143/7818	12452/16852
E	(120,129) to (120,116)	9 to 24	7406/9738	13728/9738

Measuring Size Book
INVESTIGATING MOON CRATERS UNIT

This Unit is intended to be a more flexible and open alternative to the *Comparing Lunar Crater Heights Unit*. Students are encouraged to develop their own questions about the lunar topography and be inspired by the image processing software to develop techniques for finding answers. Their questions may include concepts that are included in the *Measuring the Size of Moon Features Unit,* which goes beyond finding relative sizes to finding actual ones.

Measuring Size Book
TRACKING JUPITER'S MOONS UNIT

SA3: Simulating Orbits is an activity developed by TRA Rich Lohman and Jeff Friedman and used with the physics class at Albany High School in Albany, CA. This would be good to use before Activity III as a way to make the apparent changes in velocity of the moons a reasonable result given our edge-on view from Earth of the moons' orbits. Rich Lohman even uses it first before this Jupiter's Moons Unit..

Rich and Jeff also 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 you have RAM memory problems and cannot display more than two images at a time, try the following in Activity II and Activity III for combining images. Keep only two images displayed, adding or subtracting one to a growing composite image. DO NOT display the result in a new window. Close the single image before displaying the next one to be added to or subtracted from the growing composite.

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.

Activities I and II:

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.

Activity III: What Happens to the Moons During Six Hours?

5. Image Info:

	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 books include filter, Right Ascension, RA, and Declination, Dec, and the plate scale.

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.

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

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

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

Author's Note: Using Slice I got changes of distance of 18, 18, 18, 18, and 18 pixels. The average velocity is 18 pixels/hr.

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

Author's Note: Using Slice I got changes of pixel distance of 21, 21, 20, 19, and 18 pixels. The average velocity is 20 pixels/hr.

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

Author's Note: Using Slice I got changes of pixel distance of 13, 13, 13, 14, and 14 pixels. The average velocity is 13 pixels/hr.

10. 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.

Activity 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 velocity, 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 in Activity IV for Europa and Ganymede, it is still unclear which is which. The activity sheet mentions the relationship between orbit radius and velocity. This would seem to be a way to sort them out, but the velocity data is inconclusive on this. Theoretically the moon in the larger orbit moves at a slower velocity. 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."

Measuring Size Book
Supplementary Activity 3: Simulating Orbits.

This unit was written by Rich Loman, Albany High School, California.

SA#3: Simulating Orbits is an activity developed by TRA Rich Lohman and Jeff Friedman and used with the physics class at Albany High School in Albany, CA. This would be good to use before Activity III of the *Tracking Jupiter's Moons Unit* as a way to make the apparent changes in velocity of the moons a reasonable result given our edge view from Earth of the moons' orbits. Rich Lohman even uses it first before the Tracking Jupiter's Moons Unit. Rich and Jeff also suggested the alternate subtract and add procedure for making a composite image of all six images. To see how it helps to alternate subtracting and adding, ask students to first try adding only.

Rich uses this activity with his physics class. For pre-physics students the first 10 questions are well worth the time.

Questions **2** through **6** are instructions for making a drawing that helps understand the difference between an edge-on view and a top view of the moons of Jupiter. A version of this drawing is on the next page.

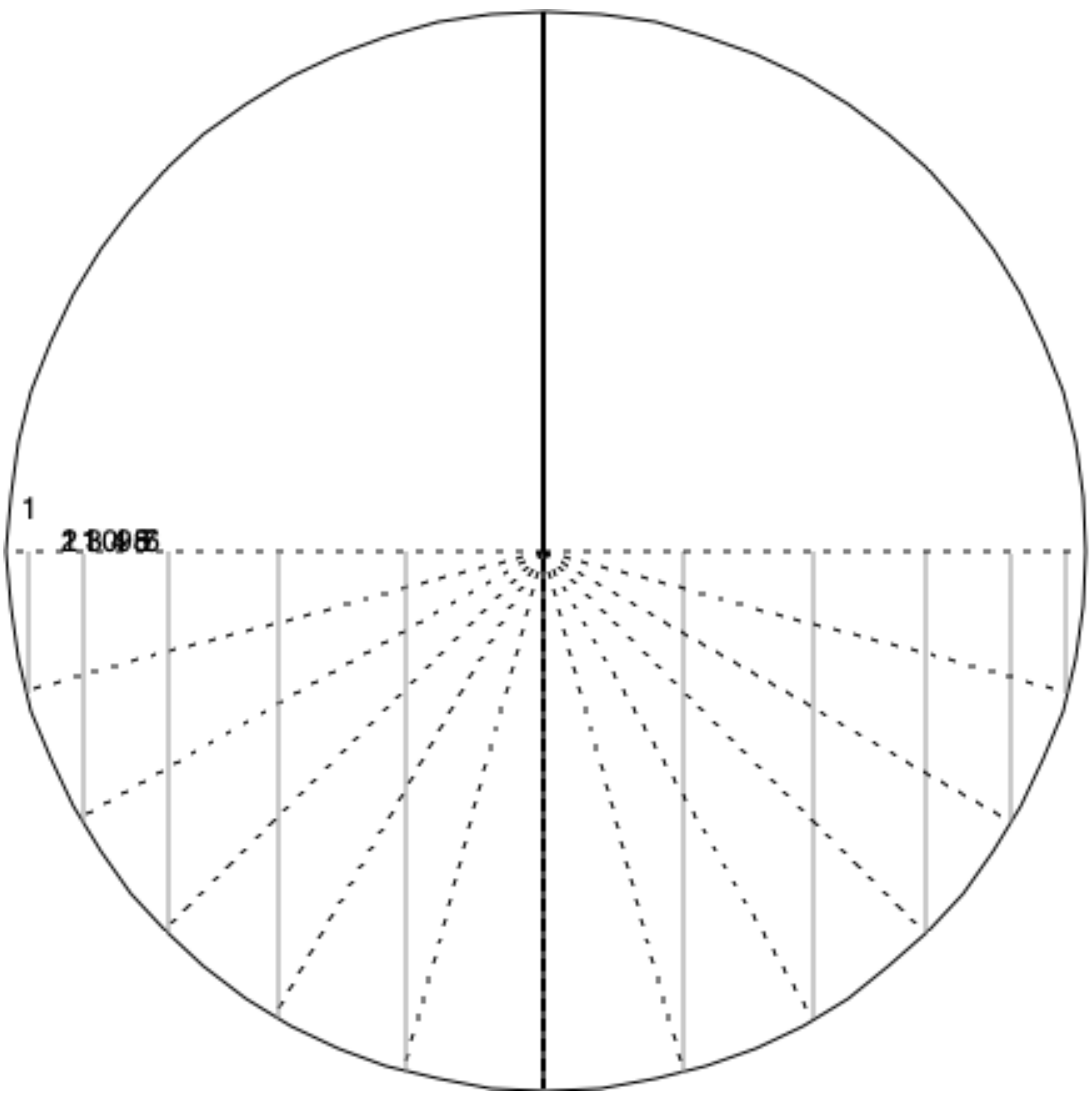
7. a) The following measurements are from the drawing.

	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12
cm	0.3	0.7	1.2	1.5	1.8	2.0	2.0	1.8	1.5	1.2	0.7	0.3

With a scale of 1 cm = 100,000 km, the distances in kilometers for the first six are:

3×10^4, 7×10^4, 1.2×10^5, 1.5×10^5, 1.8×10^5 and 2.0×10^5

Velocity is distance divided by time. Since the images were taken one hour apart, the apparent average velocity in km/hr between each of the positions is the distance in kilometers divided by 1 hour; e.g., 3×10^4 km/hr and 1.8×10^5 km/hr.



7.b) The graph of apparent average velocity vs. position number resembles a sine curve. The sine curve is characteristic of many kinds of periodic motion such as a pendulum bob, a weight suspended on a spring, and the motion of boat or a buoy in the water bobbing up and down in the waves. Question 13 is included so you can compare the graph based on measurements from a circle diagram with a mathematical sine curve.

8.(a & b) The moon moves fastest, seen edge on, as it passes by Jupiter. This corresponds to the actual velocity of the moon. This is shown graphically in the circle diagram made at the beginning of the activity.

9. This second graph is a cosine curve. A full period means continuing the graph until the moon has completed one full orbit. Question 13 is included so you can compare the graph based on measurements from a circle diagram with a mathematical cosine curve.

10 (b & c) The occultation region is where the moon passes behind the planet. Transit is when the moon passes in front of the planet. For Jupiter as seen from Earth, the moons sometimes pass above or below Jupiter, as well as sometimes being occulted by Jupiter or transiting Jupiter.

11. The distance away at the turnaround point corresponds to the orbital radius. See the circle diagram.

12. The graph of distance from the planet vs. position is a plot for a full period. Half the graph – any half – would be enough as long as you believed there was a repeating pattern. With less graph, you need to make more assumptions about the moon's motion and what part of the orbit the partial graph shows.

13. Graphs from real data should not be the same as the theoretical graph.

14. These magazines show the orbit of each of the Galilean moons plotted along a vertical time line. Because all four moons are included, and because the period and orbital radius of each moon is different, making sense of the graph can be initially challenging. In addition to each moon's orbit, the graph shows when each moon will pass above, below, behind or in front of Jupiter, when all the moons will be on the same side of Jupiter, and when two of the moons will pass each other. The more you look the more you see and the more questions it suggests.

Measuring Size Book
Supplementary Activity 5: Explanation of a Light Year

4. **A.** about 10,000,000 times faster
B. about 1,300,000 times faster
C. 300,000,000 meters
D. 1.28 light seconds
E. 1.8×10^{10} meters
F. 8.3 minutes
G. 9.5×10^{15} meters
H. 1.5×10^{17} meters (for a 15 year old)
J. about 5.5 hours

K. about 100,000 years
L. Andromeda Galaxy
M. No, because Betelgeuse is about 300 light years away.

Supplementary Activity 6: Using Angles to Measure Sizes and Supplementary Activity 7: Measuring Your Computer Screen

These activities are intended to provide hands-on classroom experiences that emphasize the practice of measuring angles and relates these to angles students measure on the images, as in the *Measuring Sizes with Images Unit*. The angles they will work with on images of stars and other astronomical objects are extremely small compared to angles they see in daily life. This could provide the basis of a classroom discussion: What does 15 degrees look like? One degree? one arc minute? One arcsecond?

Measuring Size Book
MEASURING SIZE WITH IMAGES UNIT

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 Sizes*. 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 use the Moon to get the subtended angle.

Activity I: What is a Pixel?

1. Does the color or shading vary? No

2. Does it vary when you **Zoom**? No

Activity II: Measuring Plate Scale of an Image

3. Number of pixels covered by the Moon about 650

4. 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

5. 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

Activity III: Measuring Size on a CCD Image

6. Width of Rori's screen in pixels — about 90 pixels

7. Angle covered by Rori's screen
11 inches ÷ 81 inches = — 0.136 radians

8. Plate scale of the *rori* image
0.136 radians x (206265"/rad) ÷ 90 pixels = — 310"/pixel

Activity IV Measuring the Size of Astronomical Objects

9. Width of Moon crater in pixels — about 72 pixels

10. Angle covered by crater in arc seconds
(0.99"/pixel) x 72 pixels — 71"

11. Actual size of crater in meters
d / (3.84 x 10^8 m) = 71" x (1 rad/ 206265")
d / (3.84 x 10^8 m) = 0.0003 rad
d = (0.0003 rad) x (3.84 x10^8 m) = — 1.3 x10^5 m

12. Could a house fit in this crater? — yes

13. Width of Jupiter in pixels — about 60

14. Angle covered by Jupiter in arc seconds
(0.67"/pixel) x 60 pixe — 40"

15. Diameter of Jupiter in meters
d / (7.8 x 10^{11} m) = 40" x (1 rad/ 206265")
d / (7.8 x 10^{11} m) = 0.0002 rad
d = (0.0002 rad) x (7.8 x 10^{11} m) = — 1.5 x10^8 m

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

17. Width of Sun in pixels — about 650

18. Angle covered by Sun in arc seconds
(3.0"/pixel) x 650 pixels — 1950"

19. Diameter of Sun in meters
d / (1.5 x 10^{11} m) = 1950" x (1 rad/ 206265")
d / (1.5 x 10^{11} m) = 0.009 rad
d = (0.009 rad) x (1.5 x 10^{11} m) = — 1.4 x10^9 m

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

21. Distance to Crab Nebula in meters
6000 ly) x (9.5 x 10^{15} m/ly) = 5.7×10^{19} m

22. Width of Crab Nebula in pixels about 150

23. Angle covered by Crab Nebula in arc seconds
(0.99"/pixel) x 150 pixels 149"

24. 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) = 4.1×10^{16} m

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

26. 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 10^7 ly) = 29.7" x (1 rad/ 206265")
d / (3 x 10^7 ly) = 0.00014 rad
d = (0.00014 rad) x (3 x 10^7 ly) = 4000 ly

27. Width of M51
width in pixels = about 200 pixels
angle covered = (200 pixels) x (0.99"/pixel) = 198"
d / (3 x 10^7 ly) = 198" x (1 rad/ 206265")
d / (3 x 10^7 ly) = 0.00095 rad
d = (0.00095 rad) x (3 x 10^7 ly) = 29,000 ly

28. 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

Final Challenge:

Image chosen ____________________

Field of view of entire image
512 pixels x 0.67"/pixel = 343" = 5.7'
-or-
512 pixels x 0.99"/pixel = 507" = 8.4'

Measuring Size Book

MEASURING THE SIZE OF MOON FEATURES UNIT

This unit was written by HOU teacher Hughes Pack from Northfield-Mt. Hermon School in Northfield, MA.

Materials -

Students - individual or by group

- calculator
- extra paper
- cm ruler
- scissors
- protractor

Classroom - styrofoam balls - about 10 cm diameter - best if there can be enough for student pairs.

- bright light source - 200 W light bulb on a stand should do it
- Moon maps or photos with the large crater in the *moon* image visible. This crater is *Albetignius*. - several handbooks have nice photos, :
  - (1) Peterson's Field Guide to Stars and Planet
  - (2) Good photos have been found in inexpensive ($4.95 or less) sky guides available at K-Mart, etc.
  - (3) Try also Sky Publishing Corp for Moon maps - it does appear on the $1.50 map and is labeled and named; however, it is harder to find than on a first quarter photo.
- geometry text - nice to have for students who really want to check out the reasoning in their proof

General Notes

1. Do this *Moon Measure Unit* before you assign it (don't laugh, yet!).

2. **Activity I**: we have included a diagram you can use to show how we get the ratios used to find the crater diameter.
   The relationship between arc length, radius and subtended angle is $s = r\,a$, where a is given in radians. This relationship is always true.

   As you look at the figure in step 2, think of arcs being traced out by the moon and by the crater.
   Let : S_c = crater arc length
   S_m = moon arc length
   r = the distance to the Moon. Assume that the Moon and crater are at the same distance (very close !).
   d = the linear diameter of the crater (chord length)
   D = the linear diameter of the Moon (chord length)
   Then : $S_c = r\,a_c$
   and $S_m = r\,a_m$
   divide the top equation by the bottom to get

$$\frac{S_c}{S_m} = \frac{a_c}{a_m} \quad .$$ 'a' can be in any unit here; each must be the same, however.

As the angle subtended gets very small, the values of the arc length and the chord length get closer and closer. Since $a_m = 0.5$ degrees, the arc length and the chord connecting the endpoints of the arc are VERY nearly the same length.

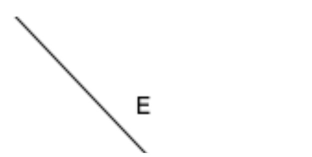
So : $S_c = d$ and $S_m = D$, which gives us $$\frac{d}{D} = \frac{a_c}{a_m}$$

We know D and a_m, so all the students have to measure is a_c in pixels and convert to arc seconds, then proceed.

3. **Activity II**: Diagrams

If students have trouble with the changing perspective in the section on Drawing the Two Triangles, you may want to do the Styrofoam ball activity using a larger ball or globe for the entire class or for small groups. Soft clay works nicely as a peak.

It is important that the height of the peak be very much smaller than the size of the moon in this activity. In figure (d) we construct ΔDEB greatly exaggerated. The problem with figure (d) is that point D of a right triangle is not actually on the surface of the moon, meaning that angle DBE is not a right triangle at all. However, in reality, the peak BE is much, much smaller than the radius of the Moon, so the error is very small and angle DBE is VERY nearly a right angle.



The Moon surface has not been included in diagrams with exaggerated triangle figures so we do not confuse the derivation. The enlargement is to show all the triangle lines on the diagram clearly.

Figure (e): there may be problems matching the triangles if the tracing or Xeroxing has distorted the image. Check it first.

4. **Activity II:** Questions:

Question 7, be aware that there can be as much as a factor of two variance when measuring the terminator distance, d. This is OK.

Question 10, you may want students to check their ratios with you before they go too far.

Question 17, you will want to think about this yourself before you are asked to explain it. The actual shadow is along the surface of the Moon from the base of the peak to the point where the shadow ends and the surface is exposed to sunlight. However, as we view the peak from Earth, we are not DIRECTLY above the peak, so we see a "lack of light" from the top of the peak to the end of the shadow. It is longer than the actual shadow by an amount that depends on how far from directly overhead we are.

Proof of Triangle Similarity. We did introduce the possibility that there are other proofs, so be prepared. All one needs for similarity is two equal corresponding angles. Of course, all three angles will then be equal. A student could also measure the sides and prove similarity by ratios of corresponding sides. Have a geometry book handy.

Answers.

1. ~ 65 pixels
2. 64 "/pixel
3. ~ 120 km
4. diagram
5. ~ 90 degrees
6. 1st Q
7. ~ 90 degrees
8. they are similar
9. proof
10. s = 10 pixels, d = 75 pixels
11. 910 pixels
12. h = (s/r) * d ; h = 0.82 pixels
13. 1 pixel = 1.9 km
14. 1.6 km
15. seems ok, not outrageous, anyway
16. ~ 20 %
17. – (open ended)
18. Albetignius , using the Sky and Telescope Moon maps (small ones)
19. 93 km , from Sky and Tel maps
20. smaller

Measuring Size Book
THE MASS OF JUPITER UNIT

This unit was written by HOU teacher Hughes Pack from Northfield-Mt. Hermon School in Northfield, MA.

Introduction

The *Tracking Jupiter's Moons Unit* is a prerequisite for this unit. 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. Appendix A is about deriving the equation for the mass of Jupiter. If there is not time or if the math level of the students is not adequate, they can work through the activity and simply use the equation given to calculate the mass. Appendix B shows a derivation for the Small Angle Approximation.

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

2. 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.

3. 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..

4. 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.

5. The distance is approximately **200 pixels**.

6. 200 pixels are equivalent to **6.1 x 10^{-4} radians**.

$$200 \text{ pixels} \times \frac{0.63''}{1 \text{ pixel}} \times \frac{1 \text{ arc minute}}{60''} \times \frac{1 \text{ degree}}{60'} \times \frac{1 \text{ radian}}{57.3^{o}} = \mathbf{6.1 \times 10^{-4} \text{ radians}}$$

7. A derivation of the equation the students use here is in Appendix B.

$D = (6.63 \times 10^{8}\text{ km}) \times (6.1 \times 10^{-4}\text{ radians}) =$ **4.0x 10^{5} km**

The actual radius is about 4.22 x 10^{5} km.

8. 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.

10. From the data here, you will get a mass of about **2.0 x 10^{27} kg**.

11. Accepted value : **1.9 x 10^{27} kg**

% difference : **about 7%**

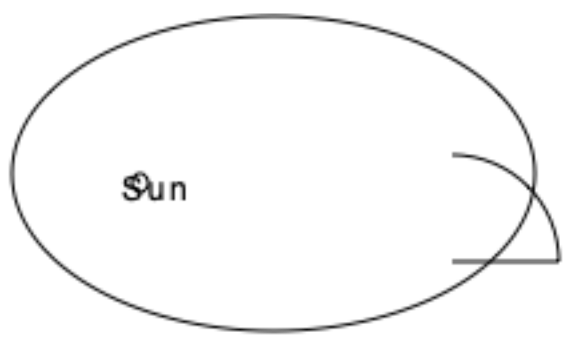
Appendix A: Deriving the Equation for the Mass of Jupiter:

While this unit primarily uses the work of Isaac Newton, he was not working in a vacuum. Scientific theories and laws are built upon the work of many different people working from the beginning of time to understand the world around us. Determining the mass of Jupiter is no exception. The scientists who have received most of the credit for the rules about orbiting bodies are Tycho Brahe (born in 1546 to a Danish noble family), Galileo Galilei (born in 1564 in Pisa, Italy), Johannes Kepler (born on December 27, 1571 in Weil, Germany) and Isaac Newton (born in 1642 in England).

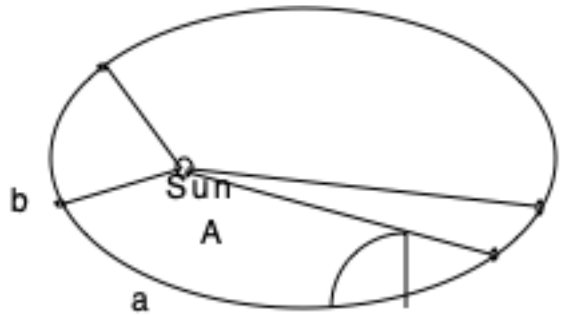
During the time from 1609 to 1619, Kepler announced three empirical laws describing the motion of planets in our solar system. (Empirical laws are laws derived from observation and experiment as opposed to theory which can come from thought alone.)

Kepler's Laws :

1. The Law of Ellipses : The orbit of each planet is an ellipse with the Sun at one focus.



2. The Law of Equal Areas : The line from the Sun to a planet sweeps out equal areas in equal intervals of time.



In the figure above the time interval from a to b is the same as the time interval from c to d for Earth as it orbits Sun. The areas swept out are equal to A in each case.

3. The Harmonic Law : The square of the sidereal period of each planet is proportional to the cube of the semi-major axis (mean radius) of its orbit.

This may be written algebraically as : $T^2 = k\,d^3$, 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.

Kepler had shown by 1621 that the four moons of Jupiter discovered by Galileo obeyed the relationship in the Harmonic Law (law #3).

Deriving the Equation

Given the first three equations, which are in the unit, here is the completion of the derivation of the equation for the mass of Jupiter.

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:

$$(4) \qquad \frac{G\,M_J\,m_m}{d^2} = \frac{m_m\,v^2}{d}$$

This equation reduces to :

$$(5) \qquad \frac{G\,M_J}{d} = v^2$$

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. Taking the relationship for v in equation (2) and substituting it into equation (5), we get:

$$(6) \qquad \frac{G\,M_J}{d} = \frac{4\,\pi^2\,d^2}{T^2}$$

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

$$(7) \qquad M_J = \frac{4\,\pi^2\,d^3}{G\,T^2}$$

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.

Measuring Brightness

Teacher Theme Notes

This Theme is intended to teach students to measure brightness using the Photometry tools in the HOU software. Photometry is the measurement of light intensity; in other words, the brightness of an object. Measurement of brightness and comparison of multiple images are skills required in many HOU units and research projects. Clear understanding of the definitions of Counts and Apparent Brightness are crucial to this. The following explanations are probably more detailed than the average student needs but are intended to provide a background for you, the teacher, to work with.

Counts: A CCD camera detects light using the photoelectric effect. The incoming photons react with the device to create a flow of electrons. The CCD Counts the number of electrons released as photons hit each pixel on the face of the CCD. This number is referred to as the Counts for that pixel and is directly proportional to the number of photons that were directed at the corresponding region of the image. Each CCD reacts differently to light, yielding a different number of electron Counts per photon. Also, even with the same CCD, the number of Counts will vary from a given source as observing conditions change. On a cloudy night, the CCD may receive less light, thus count fewer photons from a star than on a clear night.

Counts are a useful quantity for comparison of several stars on the same image. Each star on that image was observed by the same CCD and under the same observing conditions as every other star on that image. Therefore the ratio of Counts is equivalent to the ratio of brightness for those stars. In order to compare stars or any other objects on different images, a quantity for brightness that is independent of equipment or observing conditions must be used.

Apparent Brightness: The apparent brightness is the quantity all observers agree on as the brightness of a given star (if it is not a variable star) as viewed from Earth. It is independent of equipment or observing conditions.

Most reference materials use the unitless quantity, magnitude, to refer to brightness. Magnitudes are very useful when one is comfortable with logarithmic scales and operations. The magnitude scale is covered in *The Magnitude Scale Discussion Sheet* and in Supplementary Activities 13-15. However, Apparent Brightness, with units of Joules/second/meter^2 or equivalently, Watts/meter^2, can be used for simple ratios to compare the brightness of two stars, since the units cancel out.

A Brightness Conversion Table between apparent magnitude and apparent brightness is provided with this Theme. Magnitudes are given when brightness information is provided for a star, because that is the way students would find the information in common reference materials. There seem to be mixed opinions on whether it is more straightforward for students to use magnitudes or brightness (with cumbersome units). The conversion table (along with the HOU activities on the magnitude scale) is an attempt to offer both options to students and enable them to use common resource materials with their research. The goal in this Theme is to have the calculations and units be only a tool for students to use to get to the science, not something that gets them bogged down or intimidated.

The process of calibrating the Counts of a star on a CCD image involves the use of a standard star. A **standard star** is defined as one that has a known apparent brightness. In **calibration** a standard star is used that is observed under the same conditions as the target star (the star of interest). Astronomers tend to have a rigorous definition of standard star and have catalogs of the brightness of certain stars that can be used as standards. At times in the HOU curriculum we may relax the constraints to include stars that suit our purposes though not found in the catalogs.

Student Outcomes for Measuring Brightness

Upon completion of this Theme students should exhibit competence in the following skills and concepts taken from the national goals and standards for Math and Science education.

1. Familiarity with the number scale, scientific notation and appropriate use of various measurement scales.
2. Interpretation and transformations among various data representations beginning with pixels on an image and Counts, to apparent brightness, and then to magnitudes.
3. Use of ratios to convert from one type of measurement to another.
4. Use of logarithms to derive, validate and apply a Magnitude calculation.
5. Understanding the interaction between light and matter and the effect of atmospheric and instrumental effects on the measurement of brightness.
6. Understanding and the use of calibration between known and unknown quantities in scientific research.

Suggested Checklist for Assessment for Measuring Brightness

When a student is measuring the brightness of an object on a CCD image, the following concepts and skills may be evaluated:

1. Use of **Auto Aperture** or **Aperture** in measuring Counts of a star.
2. Correct use of ratios when comparing brightness of a target star to a reference star.
3. Logical set-up of equations and use of ratios for calibrating a target star with a standard star.
4. Organization and plotting of brightness data from a sequence of data.
5. Logical interpretation of a light curve to indicate a supernova type.

Follow-Up and Assessment Activities for Measuring Brightness

1. Observe a cluster of stars along with a standard star and find the apparent brightness (or magnitude) of many stars in the cluster. Use the fact that they are all in the same cluster (presumably all at the same distance) to get a range of luminosity for the stars in the cluster. What is the ratio between the brightest and dimmest star measured? Choose a method such as a histogram or scatter diagram to display the distribution of luminosity. If the distance to the cluster is known, the actual luminosity can be calculated and plotted; if not, the ratio of luminosity relative to one reference star can be calculated and plotted.

2. The term "dog-days of summer" is believed by some to come from the fact that the "dog star", Sirius, is in the same direction as the sun at mid-summer. Some folklorists state that people believed that the combined energy radiating from both Sirius and the Sun caused mid-summer days to be significantly hotter. Use the fact that the apparent magnitude of Sirius is -1 and the apparent magnitude of the sun is -26 to find the ratio of the apparent brightness of these two stars. Do you believe the energy received from Sirius significantly affects the temperature on Earth?

The difference in magnitudes of the Sun and Sirius = 25. Therefore the ratio of brightness is $(2.5)^{25} = 10^{10}$ *= 10,000,000. The extra energy of Sirius reaching the Earth during the summer days is not significant in affecting our temperature.*

3. Choose a geographic location to build a state-of-the-art telescope and explain what conditions make that location optimal.

Answers should include reference to lack of humidity, dark skies (away from city lights) and lack of turbulence. Cool, dry sites may include desert mountains or even outer space which eliminates many more sources of absorption.

4. Suppose you need to find the mass of certain objects and all you have is a balance (without an absolute scale) and a large set of identical marbles. Can you determine the ratio of two masses using the marbles with no other information? Describe a process through which you could find the mass in kilograms of each of the unknown objects. What one piece of information do you need to know about the marbles and how does this fit into the solution? First write out your solution in words and then using equations.

This example is analogous to the process of using Counts to find the brightness of stars. Since the value of Counts depends on observing conditions and the telescope used, using Counts to measure brightness is analogous to using marbles to measure mass.

The marbles can be used to find the ratio of masses of two objects with the following expression:

$$\frac{\text{mass of object 1}}{\text{mass of object 2}} = \frac{\text{\# of marbles to balance object 1}}{\text{\#of marbles to balance object 2}}$$

Since the balance does not have a scale, the mass of one object must be known to calibrate the other measurements. For instance, if the mass of one marble is known in kilograms, then the mass of unknown objects can be measured by determining how many marbles are used to balance the scales.

This is analogous to using a standard star to get the apparent brightness of a star given its brightness in Counts.

5. Given an image of two stars, one with known apparent magnitude, find the apparent magnitude of the unknown star. Suppose these stars are on separate images that were taken with the same CCD at nearly the same time. Would the same process be valid? Suppose they were on separate images that were taken by the same CCD on different nights, how could you get the apparent magnitude of the unknown star? What if they were taken with different CCD's?

If the two stars are on the same image, then the calibration between magnitudes and Counts is straightforward. This is the procedure explained in the Photometry Techniques Unit, Activity III. If the stars are on two separate images but taken by the same equipment at nearly the same time, it can be assumed the observing conditions are the same and the star can be calibrated just as if they were on the same image. If either the equipment or the observing conditions changed (the latter is most likely if the observations were at different times) then the two images cannot be used together for calibration. A star with known magnitude must have been observed under the same conditions as the unknown star to calibrate the measurement.

6. (For magnitudes activities) Use the example of a sexually transmitted disease with a 100% chance of infection. Choose a group of people with 1 person infected originally and assume an average number of partners per person in a given year. Predict how many people would be infected in a certain number of years. Calculate the number of years it would take for a certain number of the group to be infected.

7. Suppose you read that a new supernova was just found in a nearby galaxy. Explain step by step how you would proceed with observations to determine the type of the supernova.

Students should reply that they would observe the supernova every night possible for the next month or more (through the same filter each night) in order to create a light curve. They need to include a description of how to account for changing observing conditions, either by use of a reference star or calibration of each image. The light curve can then be compared to the general shape of light curves of type I and II supernovae. Features such as the slope of the curves and the number of nights between explosion and maximum light are clues to identifying the type. Some students may include a description of using spectra to measure the amount of hydrogen detected from the SN, which is the definition of the two types of SN (type II does not exhibit hydrogen, type I does). Using a *spectroscope is the correct method; however, this tool is not currently part of the image processing software*.

8. If students have not previously worked on the *Cepheid Variable Stars Unit* in the Measuring Size Book, that activity provides a challenging examination of these skills within a new context.

Image List for Measuring Brightness

SA9	*ptstar1* *ptstar2*
Photometry Techniques Unit	*ptstar1* *ptstar2* *ptnight1* through *4* *pttarg* *ptstan*
Supernova Light Curves Unit	*m51img1* through *3* *snimg1* through *12*
SA14	*mgclust*
SA15	*mgclust*
SA16	*ptstar3*
SA17	*pttarg*

Materials List for Measuring Brightness

SA10: Demonstrating Observing Conditions

pen and paper
flat clear container (such as a beaker)
clean water
dark food coloring or paint
flashlight

SA11: An Example of Calibration

table or large object

Unit by Unit Teacher Notes for Measuring Brightness

Discussion sheet

When a longer exposure time is used for an observation, more light is received from the star; however, more light is also received from the background sky. The amount of light received from the star is generally linearly proportional to the exposure time; if the exposure time is increased by a factor of four, the light received from the star will also increase by a factor of four. The distribution of light from the sky is generally random, following a Poisson statistical distribution. Some brightness measures for the sky are lower than average, some higher. The sky brightness is sometimes referred to as "noise" and is analogous to static on the radio. Poisson statistics predict that the sky brightness will increase as a square root of the exposure time; if the exposure time is increased by a factor of four, the light received from the star will only increase by a factor of two. This is caused by the influence of the lower and higher brightness values being averaged into the distribution. The result is that the signal to noise ratio (the contrast between the brightness of the star and the background sky) increases by the square root of the exposure time. If you are having trouble distinguishing your object of interest from the background sky, therefor, you will have to increase the exposure time quite a bit to get it to stand out. One major disadvantage to long exposure times is that the telescope must track (rotate along with the object to keep it in the same place on the image), and this is not a perfect process. As a result, long exposure images will tend to have some elongation of objects, all in the same direction.

Supplementary Activity 9: The Effect of Observing Conditions

3 and **4**. The angle subtended by Alpha Centauri: 3.4×10^{-8} radians = 0.007"

5. Under ideal conditions the light from Alpha Centauri should cover much less than one pixel since 0.007" (the angle subtended by Alpha Centauri) is much less than the plate scale, 0.67" (the angle covered by one pixel).

6. Since the star is much farther than Alpha Centauri (so d is much bigger), and the Diameter (D) is about the same, the angle subtended by this star must be much smaller. Therefore, under ideal conditions, it would cover even less of the image than Alpha Centauri, even less of a pixel.

7. This star covers roughly 20 pixels in diameter.

Measuring Brightness Book Supplementary Activity 10: Demonstrating Observing Conditions

1. Dark and clear weather.

2. The lights used by people (building and street lights) cause much of the light that inhibits good observing. This is often referred to as "light pollution". Late at night many of these lights are turned off.

3. The paint or food coloring should cloud the water so the message is hard to read. A bold marker may remain more visible through the cloudy water than a light pencil because of the contrast between the marker and the background.

5. The flashlight appears brighter when the overhead lights are off because our eyes adjust to the darkness and therefore can distinguish the flash light more clearly. Similarly, on a bright night, the light coming from a star does not stand out from the background sky as clearly as it would on an image with a very dark sky.

6. The heat causes turbulence in the air resulting in fluctuation of the density of the air. Light will refract as it travels through a dense airspace, so a turbulent atmosphere tends to scatter the light (bend its path in random directions), creating "bad seeing". The histogram included in this SA10 illustrates this.

7-**9**. When the water is very choppy the message should be illegible. The water does not need to be perfectly still to read it, just as there can be some turbulence during our telescope observations. However turbulence will cause the message (or star light) to smear out over more than one hole (or pixel) so the software must account for that when determining the brightness of the star.

Supplementary Activity 11: An Example of Calibration

Everyone's hand width and measurement technique is a bit different so one needs to know the actual length of one hand width, or equivalently how many hand widths fit into a known length, to use this as a measurement tool with known results.

let n = the number of hand widths that equal the length of a 2m table.

L = the length of the unknown table
N = the number of hand widths that equal the length of the unknown table.

then: $n / 2m = N / L$

so: $L = N \div (n / 2m) = (N / n) \times 2m$

Measuring Brightness Book
Photometry Techniques Unit

Below are some realistic answers to the questions asked in the introduction and activities; however, at this point, students should be making educated guesses and not be concerned with whether their answer is "right" or "wrong". To this end, the factual answers are provided below but nothing is given for those places that students are asked for a hypothesis, where all hypotheses are valid.

Activity I: Notes and Answers

The star on ptstar2 has a pixel brightness of about 8 or 10 times that of the other image (on average) so it appears brighter. This may be caused by changing observing conditions (clouds, turbulence, humidity, moonlight) or the true variance of the star itself or a combination of both these factors.

	[illegible]				
PTnight1 3488	285847				
5. counts of [illegible] 0.01					
7. count [illegible] [illegible] star	[illegible] counts of				

Activity III: Notes and Answers

9. By assuming that the conditions are identical, we can convert Counts to apparent brightness for the target star using the following formula:

$$B_t = (C_t/C_s) \times B_s$$

where B_t = the apparent brightness of the target star
B_s = the apparent brightness of the standard star
C_t = the Counts for the target star
C_s = the Counts for the standard star
(t and s are subscripts for target star and standard star respectively)

10. Counts for pttarg = 46563
Counts for ptstan = 152646

11. Apparent brightness through blue filter of ptstan = 1.6×10^{-11} W/m^2

12. Apparent brightness through blue filter of pttarg = 4.9×10^{-12} W/m^2

13. Apparent magnitude through blue filter of pttarg, m(b) = 8.2

Measuring Brightness Book

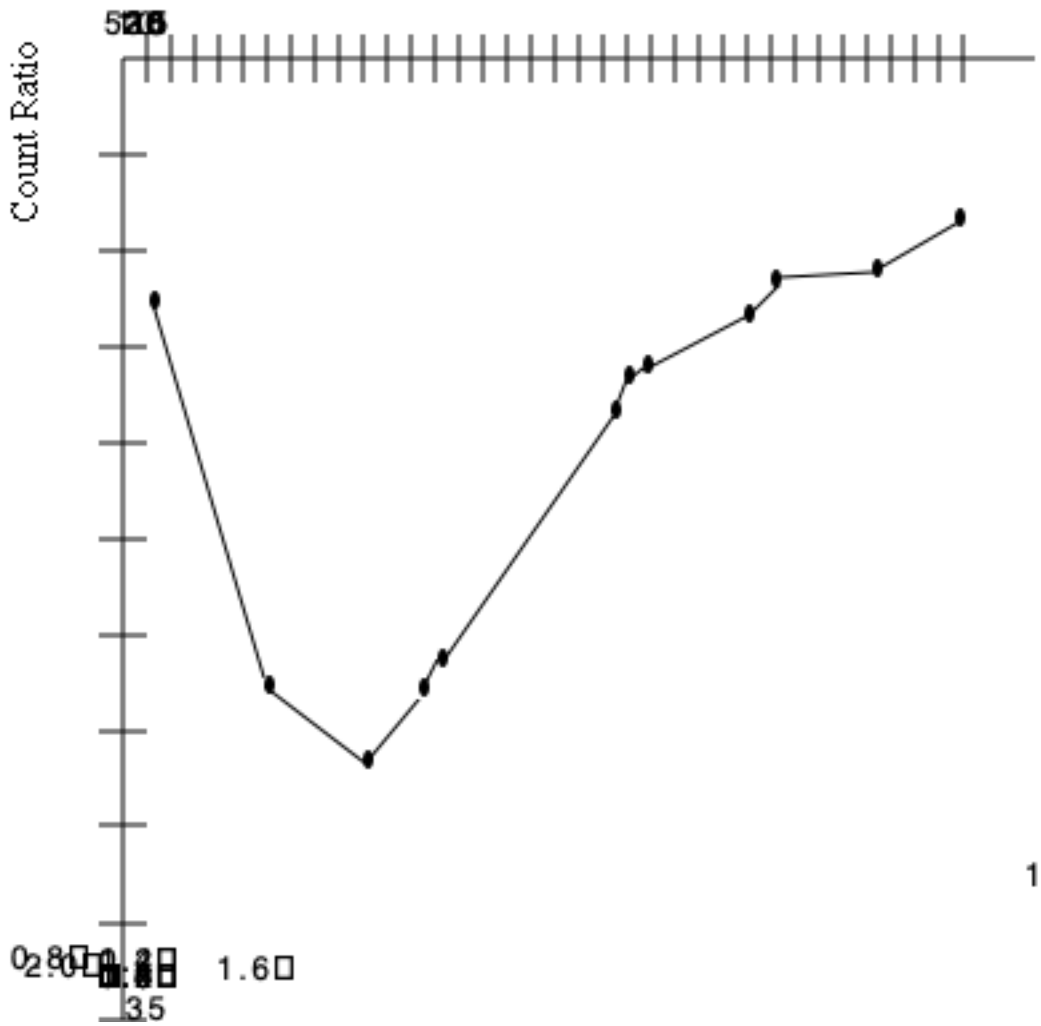
Supernovae Light Curves Unit

Activity 1:

2. The brightness of the supernova compared to the sun is Millions of times since the supernova is about the same brightness as the core of the galaxy (using the image m51img3)

Activity 2: Plotting the Light Curve of SN1994i

Count				
Counts of				
Counts of				
SNimg1 Image [illegible]	SNimg2 Night [illegible]	1	6 [illegible]	SNimg10 [illegible] 4954 [illegible]



5. Type of supernova of SN1994i: The fact that the light curve rises and falls within 20 days is a good indication that it is a type I supernova. In fact, later spectroscopic measurements have led astronomers to believe this was a type Ic supernova.

Measuring Brightness Book
The Magnitude Scale Discussion Sheet

This Discussion Sheet and associated *SA 14: Comparing the Magnitudes of Stars* are options for those classes that want to learn about the magnitude scale. Two primary, but very different reasons have been raised by teachers for including this. The first is that some students 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.

Measuring Brightness Book
Supplementary Activity 12: Some Exponential Games

1. This old standard game about exponential growth involves a person who invests “small change” in a bank. The answer is 1,073,741,823 cents, almost 11 million dollars.

2. Each generation has 3^x people, where x is the number of the generation. Similar to the last activity, students can predict the number of people in a given generation, or conversely, predict which generation would have a given number of people (power of 3). Having done the latter, they have actually computed the log base 3 of the number of people to get the generation number.

$n = 3^x$ where n = the number of people in the generation and
x = the number of the generation

$$\mathbf{\log_3(2187) = 7.}$$

Star Cards Game. The game is based on 25 so it is similar to the magnitude scale, which is based on 2.5, but without the problem with decimals. Students may also get a bigger kick out of using $10,000,000 bills. It could certainly work with other denominations if preferred. The key is to keep the difference in magnitudes as a multiplication in money and to have the lower magnitude win.

On the next page is a list of stars with their magnitudes and spectral types. The spectral type is just for your information, but the names and magnitudes may be used to create star cards for the Magnitudes Card game using the example star card as a model to create your own. This could be a student activity and could include coloring the cards to match the spectral type or labeling the cards with the constellation.

Also provided in SA12 is a list of the payments associated with the game. You will need bills in the following denominations to play the game efficiently:

$25, $100, $500, $1000, $5000, $10000, $50000, $100000, $500000, $1000000, $5000000

[redacted]

STAR NAME	M(V)	SPECTRAL TYPE
alpha Pavo	1.93	B3
beta Pavo	3.43	A5
alpha Pegasus	2.5	B9 or A0
beta Pegasus	2.5	M2
gamma Pegasus	2.84	B2
epsilon Pegasus	2.31	K2
zeta epsilon	3.46	B8
eta Pegasus	2.96	G8
kappa Pegasus	4.27	F5
mu Pegasus	3.5	G8
37 Pegasus	5.47	F5
85 Pegasus	5.75	G3
alpha Perseus	1.79	F5
beta Perseus	2.15	B8
rho Perseus	3.30	M4
Kapteyn's star	8.8	M0
alpha Pisces	3.96	A2
van maanen's star	12.4	G0
gamma Sagittarius	2.97	K0
delta Sagittarius	2.71	K2
epsilon Sagittarius	1.81	B9
zeta Sagittarius	2.61	A2
eta Sagittarius	3.51	M3
lambda Sagittarius	2.80	K2
pi Sagittarius	2.89	F2
phi Sagittarius	3.20	B8
beta Scorpius	2.55	B0

Measuring Brightness Book
Supplementary Activity 13: Magnitude Calculations

How many times brighter is:

1. A 5th magnitude star than a 10th magnitude star: *100*
2. A 7th magnitude star than a 17th magnitude star: *10000*
3. A 3rd magnitude star than a 5th magnitude star: *6.25*
4. A 3rd magnitude star than a 6.5 magnitude star: *25*
5. A 12th magnitude star than a 22.5 magnitude star: *16000*
6. Our sun (-26 magnitude) than a 15th magnitude star: *25,000,000,000,000,000*

What is the magnitude of a star if:
7. It is 100 times dimmer than a 12th magnitude star? *17th*
8. It is 10,000 times brighter than a 12th magnitude star? *2nd*
9. It is 625 times brighter than a 11th magnitude star? *4th*
10. It is 25,000 times dimmer than a -5 magnitude star? *6th*
11. It is 100,000,000 times brighter than a 5th magnitude star? *-15*

Supplementary Activity 14: Comparing the Magnitudes of Stars

The formula for the difference in magnitudes for stars 1 and 2 can be derived 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 $n = m_1 - m_2$

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

(note that this expression is correct whether B2 is greater than, less than, or equal to B1)

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)

$$\log_{10}(B_2/B_1) = \log_{10}[(2.512)^n]$$
$$\implies \log_{10}(B_2/B_1) = n\,[\log_{10}(2.512)]$$
$$\implies \log_{10}(B_2/B_1) \div \log_{10}(2.512) = n$$
$$\log_{10}(2.512) \approx 0.4 \implies 1/\log_{10}(2.512) \approx 2.5$$
$$\implies 2.5\log_{10}(B_2/B_1) = n$$

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

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

An alternative derivation goes like this:

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

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

$\implies B_2/B_1 = [(10)^{2/5}]^n$ 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:

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

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:

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

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 $2.5^{3.2}$ or 15.6 times brighter. For the second sample, 2.5^4 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.

Measuring Brightness Book
Supplementary Activity 15: 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 unit-less. 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.

Given the definition of absolute magnitude, use the definition of apparent brightness, the difference of magnitudes equation (both given in *SA 15)*, and algebra to get the distance modulus.

$B = L/4\pi d^2$	definition of apparent brightness, B where d = distance to the star

L = luminosity of the star

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

===>	$m - M = 2.5 \log [(L/4\pi(10\ pc)^2) \div (L/4\pi d^2)]$	from the magnitude equation
===>	$m - M = 2.5 \log [(1/(10\ pc)^2) \div (1/d^2)]$	$L/4\pi$ cancels
===>	$m - M = 2.5 \log [d/(10\ pc)]^2$	invert fractions
===>	$m - M = 5 \log [d/(10\ pc)]$	laws of logarithms
===>	$m - M = 5 \log (d) - 5 \log(10\ pc)$	laws of logarithms

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

This equation is valid when d is in parsecs.

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

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

$M = 7 - 11.5 = -4.5$

3. $m(v) = 12.0$

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

$M = 1.27$

Measuring Brightness Book
Supplementary Activity 16
Tools for Measuring Brightness: Auto Aperture & Aperture

1. Counts for star	271960
2. Counts of average sky pixel	about 30
3. Counts for average star pixel (this answer could vary widely)	about 6000
4. Counts of star light per pixel	about 650-950
5. Number of pixels within star	about 300-350
6. Total Counts of star light	about 200,000 - 300,000

Supplementary Activity 17: Measuring the FWHM of a Star

This activity is for pedagogical purposes mostly, since the software measures the FWHM automatically when using **Find**. However, FWHM is a common tool used in many branches of observational astronomy so some students may be interested in learning this. It is also an interesting application of graphical analysis.

1. The height of the peak	(1538 -(-7)) = 1545
2. The width of the base	roughly 20
3. The FWHM	5
4. Using Find, FWHM is	4.94

Measuring Distance

Teacher Theme Notes

Distance is one of the most elusive parameters for astronomers since, in general, it cannot be measured directly. A common method for inferring distance is through the use of standard candles, objects whose brightness is known on an absolute scale. When the apparent brightness of these objects are measured, this can be compared to their known absolute quantity of brightness and the distance calculated. Standard candles such as Cepheid Variable stars and certain types of supernovae are the basis for most distance calculations performed to determine the size, and in turn, the age of the universe.

The light emanating from a star follows a distribution that is inversely proportional to the square of the distance from the source, more commonly referred to as the $1/r^2$ rule. This distribution is fundamental in physics and astronomy because it applies to any quantity emanating from a spherically symmetric source. Examples of a $1/r^2$ distribution in physics include: the strength of the gravitational field surrounding the Earth, the strength of the electric field surrounding a point charge such as a proton or electron, and, as in this book the intensity of light from a spherical light bulb or a star.

The Measuring Distance Theme is intended to develop an intuitive understanding of the $1/r^2$ rule and about the structure and development of a cosmological distance ladder. The HOU activities involved assume a general understanding of the photometry techniques contained in the Measuring Brightness Theme.

Student Outcomes for Measuring Distance:

Upon completion of this Theme student should exhibit competence in the following skills and concepts taken from the national goals and standards for Math and Science education:

1. Derivation and applications of functions and ratios within the context of a scientific technique.
2. Interdependence of multiple variables in defining and solving a problem.
3. Use of ratios to convert from one type of measurement to another.
4. Use of geometry to derive, validate and apply a Small Angle Approximation.
5. Use of spherical geometry within the context of a scientific investigation.
6. Analysis involving an inverse square distribution.
7. Interpretation of periodic functions.
8. Application of the ideal gas law.
9. Application of energy conservation and energy transformation.
10. Contributions to science as an ever changing, ever growing thought process.

11. Questioning our place in the universe.

Suggested Checklist for Assessment for Measuring Distance:

While a student is analyzing an image and calculating distance, the following concepts and skills may be evaluated:

1. Was the choice of standard candles such as Cepheid Variable stars made correctly?
2. Was the luminosity or absolute magnitude inferred correctly from the given data?
3. Was the inverse square law used to determine distance from luminosity and apparent brightness
4. Was a reasonableness test used for evaluating distance calculations; e.g., was the distance found for a star greater than the distance to Pluto and less than the distance to another galaxy?

Follow-Up and Assessment Activities for Measuring Distance:

1. Construct your own distance ladder to measure distances within your town, on the Earth, within our solar system, and within the universe.

2. Choose an image of an object with known luminosity (a Cepheid, the brightest galaxy in a cluster, a type I supernova at maximum brightness) and determine its distance.

3. Use the data from the *Supernova Light Curves Unit* in the Measuring Brightness book to determine the distance to the supernova in M51. To do this a new image of M51 with a standard star image will be needed to calibrate the old images.

Image List for Measuring Distance:

Determining Distance or Luminosity Using Apparent Brightness Unit	*ablstar*
Cepheid Variable Stars Unit	*may06cep* *may08cep* *may10cep* *may11cep* *may14cep* *may15cep* *may18cep* *may21cep*

Materials List for Measuring Distance:

Supplementary Activity 18: Techniques on Measuring Distance
Several flashlights
A dark hallway

A small object (book)
A large object (table)

Supplementary Activity 19: Using a Light Bulb to See How Brightness Varies with Distance
Light source
Meter sticks or tape measures
Large dark room or hallway
Cadmium-Sulfide photocell - such as Radio Shack #276-1657 @ $1.98 for a package of 5.
Ohm meter

Supplementary Activity 20: Measuring Spherical Distributions
(for each group of students)
3 different sized spheres; e.g., ping-pong ball, tennis ball, and soccer ball.
Cloth Tape measure
Scissors
Aluminum foil or plastic wrap
Spherical-shaped Balloon
Cloth Tape measure
Small sheet of clear plastic

Supplementary Activity 22: Examining Periodicity
A basketball

Supplementary Activity 23: Demonstrating Gas Laws
A balloon
An empty, dry glass bottle (about 10-12 oz.)
A pan of boiling water
A pan of very cold water
An empty, dry plastic two-liter soda bottle
A plastic temperature strip (such as for an aquarium)

Unit by Unit Teacher Notes for Measuring Distance Book

Supplementary Activity 19: Using a Light Bulb to See How Brightness Varies with Distance

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 $1/r^2$ rule with distance. When plotting light reading vs. distance, the curve should be a parabola. The relationships, $B \alpha D$ and $B \alpha D^2$, 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 $B \alpha 1/D$ 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.

Measuring Distance Book:
Supplementary Activity 20: Measuring Spherical Distributions

Activity I: The key to the success of this activity is to have the dots on the balloon evenly and densely spaced. The more dots there are, the less significant errors in spacing become. Using a grid to draw the dots may make it simpler to space them evenly. If their patch contains many dots at the first radius they should see the number roughly decrease by a factor of 4 when they double the radius and by a factor of 9 when they triple the radius. Similarly, the area of the square on the other side of the balloon will increase by the same factor.

Activity II: The point of this activity is for students to gain a clear understanding of the concept of surface area and then see that the surface area of a sphere is proportional to r^2. A few suggested techniques for measuring the surface area of the spheres are:

1. Wrap each sphere in foil, being careful not to fold or crinkle the foil that is in contact with the sphere. Cut away excess foil that is overlapping or not in contact with the sphere. Carefully unwrap the foil and lay it as flat as possible without tearing it. Divide the foil into segments with shapes of regular geometric figures, such as circles, rectangles, and triangles, and use the given formulae to estimate the area of each segment. Add them up to get the approximate surface area of the sphere. Note: the most accurate approximation I found was to approximate the area of the entire square originally used to cover the sphere and subtract the area of the approximate triangles I cut away.

2. The surface area of a sphere is exactly equal to the surface area of an open cylinder (without the top and bottom circles) in which the sphere fits snugly. Such a cylinder is of equal radius and has a height equal to the diameter of the sphere. Therefore if you cut a strip of paper that has width equal to the diameter of the ball and just wraps around the circumference of the ball, the area of the paper will be the surface area of the ball.

3. One group at an HOU workshop was given this task and cut many thin strips of tin foil with known area. They covered the ball with whole and partial strips and then simply counted the number of strips. They multiplied the area of each strip by the total number of strips to get the surface area of the sphere. Their answer was very accurate.

Supplementary Activity 21:
A Thought Experiment for Brightness and Distance

This activity provides an alternative context for understanding the ideas of luminosity, apparent brightness and the relationship of apparent brightness to distance. Though the idea of imaginary spheres collecting paint is whimsical, it is analogous to observing stars. The paint is conserved; no matter how far out the sphere, it collects the same amount of paint in the same time period. However, it gets spread more thinly the further out the sphere. What is more, the relation between paint per unit of area and distance away is derived by computing the total surface area over which it is spread. From this comes the $1/r^2$ law, theoretically derived rather than experimentally, as in *SA19: Using a Light Bulb to See How Brightness Varies with Distance*.

1. Paint on:
- **A.** SHELL1 for 1 sec: 1000 g
- **B.** SHELL1 for 2 sec: 2000 g
- **C.** SHELL1 for 10 sec: 10,000 g
- **D.** SHELL2 for 1 sec: 1000 g
- **E.** SHELL3 for 1 sec: 1000 g
- **F.** SHELL3 for 10 sec: 10,000 g

2. Surface area of each shell:
- **A.** SHELL 1: 1257 sq cm
- **B.** SHELL 2: 5027 sq cm (4 times Shell 1)
- **C.** SHELL 3: 11,313 sq cm (9 times Shell 1)
- **D.** SHELL 4: 20,106 sq cm (16 times Shell 1)

3.
- **A.** The paint that would land on half of SHELL1 each second: 500 g
- **B.** The paint that would land on one quarter of SHELL1 each sec: 250 g

4. For a 1 cm^2 patch:
- **A.** The ratio of the patch to SHELL1: $1/1257 = 8 \times 10^{-4}$
- **B.** The amount of paint on patch per second: $(8 \times 10^{-4})(1000\ g) = 0.8\ g$

5. The amount of paint on a 1 cm^2 patch:
- **A.** On SHELL1 for 2 sec: 0.8 g x 2 = 1.6 g
- **B.** On SHELL1 for 10 sec: 0.8 g x 10 = 8 g
- **C.** On SHELL2 for 1 sec: 2 g
- **D.** On SHELL3 for 1 sec: 0.09 g
- **E.** On SHELL3 for 10 sec: 0.9 g
- **F.** On SHELL5 for 1 sec: 0.03 g

6. 1000 grams per second, equivalent to the amount of light emitted per second by a star. (see the *Photometry Techniques Discussion Sheet* in the Measuring Brightness Book.)

7. Apparent Brightness. This is the amount of paint collected per second on a 1 sq cm patch. For light Apparent Brightness is The amount of light reaching Earth per second from a star under ideal conditions. The units for apparent brightness are Watts/meter^2 . (see the *Photometry Techniques Discussion Sheet* in the Measuring Brightness Book.)

SHELL 1: 1000/1257 = 0.8 g/sec/cm^2
SHELL 2: 1000/5027 = 0.2 g/sec/cm^2
SHELL 3: 1000/11310 = 0.09 g/sec/cm^2
SHELL 4: 1000/20106 = 0.05 g/sec/cm^2

Measuring Distance Book:
Determining Distance and Luminosity Using Apparent Brightness Unit

1.
Counts for Star A: *444*
Counts for Star B: *3180*
Counts for Star C: *215177*

2. Use the equation:

$$\text{Apparent Brightness} = \frac{\text{Luminosity}}{4\pi d^2}$$

Since the stars are on the same image, observing conditions are identical so the ratio of the Counts is equivalent to the ratio of apparent brightness. Remember, apparent brightness is the brightness reaching the Earth but before it enters our atmosphere whereas Counts is a measure of the brightness after passing through the atmosphere and reacting with the CCD camera. When the observing conditions are the same, for instance when the stars are in the same image, then the same fraction of the light from each star is absorbed by the atmosphere and the CCD reacts to the light in the same proportions. This is why the ratios are equal.

Let: C_A = Counts of Star A
C_C = Counts of Star C
L_A = Luminosity of Star A
L_C = Luminosity of Star C
d_A = distance to Star A
d_C = distance to Star C

then: $$\frac{C_C}{C_A} = \frac{\dfrac{L_C}{4\pi(d_C)^2}}{\dfrac{L_A}{4\pi(d_A)^2}}$$

since the distances are assumed to be equal the denominators cancel out and leave:

$$\frac{C_C}{C_A} = \frac{L_C}{L_A}$$

Star C is $\frac{215177}{444} = 485$ times more luminous than Star A.

3. Again, use the equation:

$$\frac{C_C}{C_A} = \frac{\dfrac{L_C}{4\pi(d_C)^2}}{\dfrac{L_A}{4\pi(d_A)^2}}$$

but this time you assume the luminosities are equal so the numerators cancel and leave:

$$\frac{C_C}{C_A} = \frac{\frac{1}{4\pi(d_C)^2}}{\frac{1}{4\pi(d_A)^2}}$$

which can be rewritten (by inverting and multiplying) as:

$$\frac{C_C}{C_A} = \frac{4\pi(d_A)^2}{4\pi(d_C)^2}$$

the 4π's cancel and leave:

$$\frac{C_C}{C_A} = \frac{d_A{}^2}{d_C{}^2}$$

taking the square root of both sides gives:

$$\text{sqrt}\left(\frac{C_C}{C_A}\right) = \frac{d_A}{d_C}$$

which can be inverted and written as:

$$d_C = \text{sqrt}\left(\frac{C_A}{C_C}\right) d_A$$

Star A is $sqrt(\left(\frac{215177}{444}\right) = 22$ times farther away than Star C.

4. Apparent brightness of Star C: *1.0 x* 10^{-11} *W/m*^{2}
Apparent brightness of Star A: *2.0 x* 10^{-14} *W/m*^{2}
Apparent brightness of Star B: *1.5 x* 10^{-13} *W/m*^{2}

5. Luminosity of the Star A in Watts: *2.9 x* 10^{24} *W*
Luminosity of the Star B in Watts: *1.9 x* 10^{26} *W*
Luminosity of the Star C in Watts: *9.9 x* 10^{26} *W*

Measuring Distance Book:
Cepheid Variable Stars Unit

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.

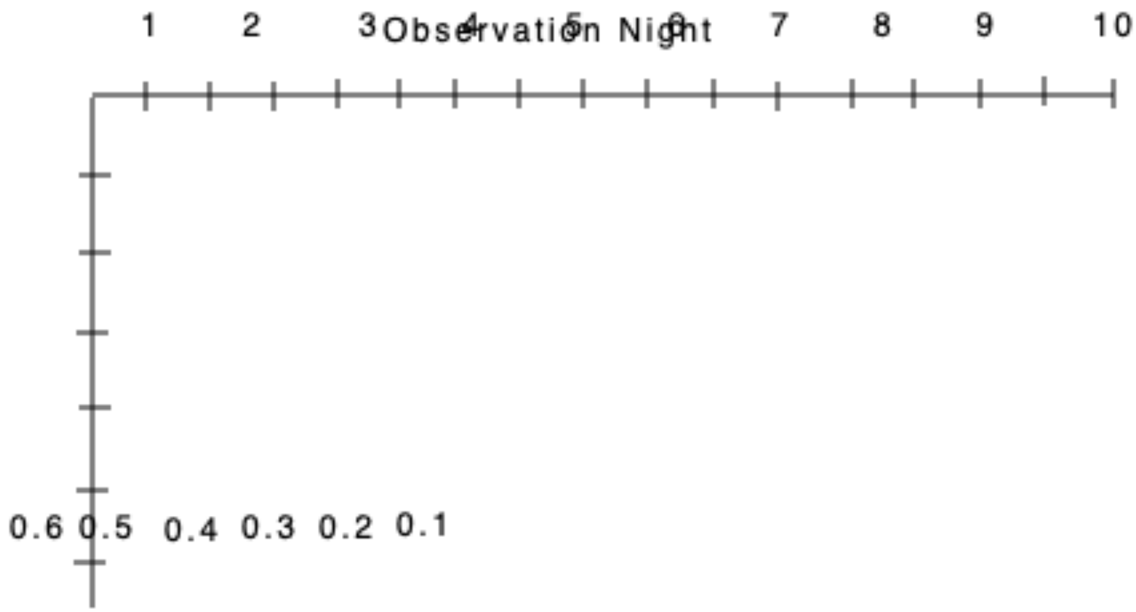
The thermodynamics that make Cepheids so interesting involve the pulsation of the star caused by heating and cooling of the gas. Most stars experience pulsations at each new evolutionary stage, but the pulsations dampen and the star reaches thermal equilibrium. In a Cepheid the pulsations remain periodic 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.

Activity 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.

1. and 2.

	1746							
	3488	285847						
Count	May06							

3.



4. Period of the Cepheid: 8 days.

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

6. Luminosity of Cepheid in Watts: 1.14 x 10^{29} W to 1.71 x 10^{29} W

7. 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/m^2 ===>

Apparent brightness of Cepheid = (0.3)(2.28 x 10^{-12} W/m^2) = 6.84 x 10^{-13} W/m^2

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 any form the student comes up with is fine as long as it gets the job done.

8.. Distance to the Cepheid in meters:

$$\text{Apparent Brightness} = \frac{\text{Luminosity}}{4\pi d^2}$$

$$\Longrightarrow \text{Distance} = \text{sqrt}\left[\frac{\text{Luminosity}}{4\pi(\text{Apparent Brightness})}\right]$$

$$\Longrightarrow \text{Distance} = \text{sqrt}\left[\frac{1.14 \times 10^{29}\ \text{W}}{4\pi(6.84 \times 10^{-13}\ \text{W/m}^2)}\right] \text{to sqrt}\left[\frac{1.71 \times 10^{29}\ \text{W}}{4\pi(6.84 \times 10^{-13}\ \text{W/m}^2)}\right]$$

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

9. Distance to the Cepheid in light years:

Distance = 12000-15000 ly

Measuring Color

Teacher Theme Notes

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.

Student Outcomes for Measuring Color

Upon completion of this Theme students should exhibit competence in the following skills and concepts taken from the national goals and standards for math and science education:

1. Derivation and applications of functions and ratios within the context of a scientific technique.
2. Construction and interpretation of plotted data with both clear and ambiguous results.
3. Interdependence of multiple variables in defining and solving a problem.
4. Familiarity with logarithmic scaling and functions.
5. Familiarity with the properties of light, specifically regarding color.
6. Understanding of the relationship between color and temperature.
7. Ability to classify objects and identify trends and patterns within a data set.
8. Judgment about strong and weak conclusions drawn from collected data.

Suggested Checklist for Assessment for Measuring Color

When a student is measuring the color of a star on a CCD image and using the HR Diagram the following concepts and skills may be evaluated:

1. Were there images of the star through two different filters (presumed here as B and V) and images of the standard star for each filter?

A. Are the standard stars taken at nearly the same time and location in the sky as the target star?
B. Are the exposure times for the standard and target stars the same or has any discrepancy been accounted for in calibration?

2. Was calibration performed correctly to determine the apparent brightness (or magnitude) of the target star through each filter?
    A. Was the data organized in a way that ensures the Counts for each star through each filter are being used correctly?
    B. Were ratios set up and calculated correctly?
    C. Were the apparent brightness and magnitude values converted correctly using the Brightness Conversion Table (or other reference)?
3. Was the color and temperature of the star found correctly using the B–V index and reference material?
4. Were all possible locations on the HR Diagram identified for a given star? (e.g., if the star is red, it could be a red giant or a red main sequence star)
5. Was distance information used in accordance to the inverse square law to determine luminosity and, in turn, the specific location on the HR Diagram for a given star?

Follow-Up and Assessment Activities for Measuring Color

1. Observe a star cluster through B and V filters (with standard star images). Find the color and apparent brightness of many stars in the cluster to create an HR Diagram for the cluster.

2. Given the B–V index for a star, identify the possible locations on the HR Diagrams for the star. Define a procedure for determining the actual location of the star on the HR Diagram.

3. Study true color photographs of star clusters or star formation regions. Predict the approximate B–V index for each of the stars. Request observations of the same region through a B and V filter (along with standard stars). Measure the B–V index for the stars and compare with the predictions.

4. Study more about blackbody radiation and Wien's law.

5. Study physical phenomena, other than temperature, that effect the color of light. These include scattering of light and chemical abundance measured using spectroscopy.

6. Study a candle flame, describe the various colors and predict which part of the flame is hotter and which is cooler.

7. Explain why a false color palette of one HOU image (an image taken through one filter) could not represent the true color distribution of an object. Explain what would have to be done for HOU to have real color imaging.

Image List for Measuring Color

Supplementary Activity 24	*btarg1*
Measuring Color of Stars Unit	*btarg1* *vtarg1* *bstan1* *vstan1*
•	*btarg2* *vtarg2* *bstan2* *vstan2*
	btarg3 *vtarg3* *bstan3* *vstan3*
	btarg4 *vtarg4* *bstan4* *vstan4*

Materials List for Measuring Color

Supplementary Activity 24:

A prism or diffraction grating.
White paper and colored pencils, crayons, or markers in
red, orange, yellow, green, blue, and violet.
A ray box or bright light with black paper to create a single ray of light.
Red, yellow and blue filters made of transparent plastic or cellophane.
Colored paper (red, yellow, blue, green, orange, white).

Supplementary Activity 25:

An incandescent light controlled by a rheostat (such as an aquarium lamp).

Unit by Unit Teacher Notes for Measuring Color

Measuring the Color of Stars Discussion Sheet

Supplementary Activities 12 & 13 in the Measuring Brightness Book may serve to give an intuitive feel for magnitudes, even for those students who are not going to do calculations with magnitudes. If the magnitudes become burdensome in trying to convey the idea of the B–V index, you may want to try some of those activities. If students are having difficulty with the idea of using a yellow and blue filter to measure a red star, set up a red light bulb and have them look at it through the two filters. They will see it is brighter through the yellow than the blue filter.

Supplemental Activity 24: Observing Colors

For students who are already familiar with refraction and the visible spectrum, this section can easily be omitted. However, the students will be expected to know the order of the colors in the spectrum, so this may be a good reminder.

The point should be emphasized and reemphasized that the filters serve to block out all light except light of the color of the filter. Many students think that a filter changes the color of the light. They also may need to be reminded again and again that the color palette used to display the star has nothing to do with the actual color of the star.

3. Which color looks darkest through the red filter? <u>blue or green</u>
4. Which color looks brightest through the blue filter? <u>blue</u>

6. For each image, decide which filter makes the star appear brightest, medium and dimmest.

Blue palette:	brightest filter	<u>blue</u>
	middle filter	<u>yellow</u>
	dimmest filter	<u>red</u>
Red palette:	brightest filter	<u>red</u>
	middle filter	<u>yellow</u>
	dimmest filter	<u>blue</u>

7. Suppose a red filter were used on the telescope when observing a very blue star. Would the image appear brighter or dimmer or the same as when no filter were used at all?

brighter <u>dimmer</u> no change

8. Suppose a blue filter were used on the telescope when observing a very blue star. Would the image appear brighter or dimmer or the same as when no filter were used at all?

brighter <u>dimmer</u> no change

Question 8 is tricky. Students may think there will be no change since all of the star's blue light will still pass through. They need to realize for a blue star that blue is the dominant color emitted, not the only color. This means the blue filter will still block out some of the star's light, although not as much as the red filter which blocks out virtually all of the dominant color emitted by the star.

Supplemental Activity 25: 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.

2. What color is the light when the rheostat is on high? <u>blue</u>

3. What color is the light at a middle setting? <u>yellow</u>

4. What color is the light at the lowest setting? <u>red</u>

5. At what setting do you think the light bulb is coolest? <u>low</u>

6. At what setting do you think the light bulb is hottest? <u>high</u>

7. What color would you expect a very hot star to appear? <u>blue</u>

8. Would a very hot star have a high or low B–V index? <u>low</u>

9. What color would you expect a relatively cool star to appear? <u>red</u>

10. Would a cool star have a high or low B-V index? <u>high</u>

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

A. Apparent brightness? <u>become less</u>
B Luminosity? <u>unchanged</u>
C. Color? <u>remain unchanged</u>

Measuring the Color of Stars with Images Unit

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 72 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 5.83×10^{-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 B_t = the apparent brightness of the target star
B_s = the apparent brightness of the standard star
C_t = the Counts of the target star
C_s = the Counts of the standard star

Then $B_t / B_s = C_t / C_s$

so $\mathbf{B_t = (C_t / C_s) B_s}$

For btarg1 $B_t = (131801/46563)\ 5.83 \times 10^{-12} = 1.65 \times 10^{-11}$
For vtarg1 $B_t = (90647/82695)\ 5.77 \times 10^{-12} = 6.32 \times 10^{-12}$

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.

1. Counts of	Counts of Star2	Counts of	2. Apparent	3. Apparent	4. App
Star1	131801	82695	5.83 E -12	1.65 E -11	6.9
	254410	88844÷ 3 =	1.94 E-12	1.67 E-11	6.9
	54922	125794 139095	7.06 E-12	3.08 E-12	8.7
Star4	527067 4456		1.47 E-11	1.04 E-11	7.4
	0.5				

Measuring Color Book
Using the HR Diagram Unit

This unit uses the data gathered in the *Measuring the Color of Stars With Images Unit*, in particular for stars 1 and 3 which turn out to be white and orange-red respectively.

1. The HR Diagram shows that white stars can either be white main sequence stars or white dwarfs. Similarly orange and red stars can either be main sequence stars or giants. To settle this ambiguity one needs to know the luminosity of the star.

2.
a. Assuming that both stars are 1000 on the main sequence then the white star, star 1, would have a luminosity of about 1000 times that of the sun and the orange-red star, star 3, would have a luminosity of about 1/2 of the sun.

b. The apparent brightness in V for star 1 = 6.32×10^{-12} W/m^2
The apparent brightness in V for star 3 = 4.19×10^{-12} W/m^2

c. $$\textbf{apparent brightness} = \frac{\textbf{Luminosity}}{4\pi d^2}$$

where d = the distance to the star

this can be written as:

$$4\pi d^2 = \frac{\textbf{Luminosity}}{\textbf{apparent brightness}}$$

or

$$d = \text{sqrt}\left[\frac{\textbf{Luminosity}}{4\pi(\textbf{apparent brightness})}\right]$$

So the ratio can be written as:

$$\frac{\textbf{distance1}}{\textbf{distance3}} = \frac{\text{sqrt}\left[\frac{\textbf{Luminosity1}}{4\pi(\textbf{apparent brightness1})}\right]}{\text{sqrt}\left[\frac{\textbf{Luminosity3}}{4\pi(\textbf{apparent brightness3})}\right]}$$

substituting values for star 1 and star 3:

$$\frac{\textbf{distance1}}{\textbf{distance3}} = \text{sqrt}$$

= sqrt (6630) = 81

Star 1 is 81 times farther away than star 3.

3.

$$\frac{\textbf{distance1}}{\textbf{distance3}} = \text{sqrt}$$

= sqrt (331487) = 576

Star 1 is 576 times farther away than star 3.

Hands-On Universe™ and the Science and Math National Standards

HOU is a program in which students learn science and math in the context of astronomy investigations. Both the content and the pedagogy of HOU conform to many of the National Research Council, NRC, and the National Association of Teachers of Mathematics, NCTM, standards. HOU emphasizes:

1. Investigations and inquiry as the mode of learning.
2. Students taking responsibility for their own learning.
3. Integration of science and math as skills and concepts used in the context of real phenomena.
4. Students working collaboratively, sharing data and data analysis as well as questions and results.
5. Technology used as a tool to facilitate student investigations.

A dominant emphasis of both standards is that learning must be an active process. "The *Standards* rest on the premise that science is an active process. Learning science is something that students do, not something that is done to them. 'Hands-0n' activities, while essential, are not enough. Students must have 'minds-on' experiences as well." NRC page 2.

NRC Science as Inquiry Standards: "Science as inquiry is basic to science education and a controlling principle in the selection of students' activities."

NRC Teaching Standard A is about science as an inquiry-based program. "...inquiry into authentic questions generated from student experiences ... focus inquiry predominantly on real phenomena ... where students are given investigations or guided toward fashioning investigations that are demanding but within their capabilities."

NRC Teaching Standard B: Facilitating learning. "Support inquiries ... discussions ... challenge students to accept and share responsibility for their own learning ... model the skills of scientific inquiry, as well as the curiosity, openness to new ideas and data, and skepticism that characterizes science."

NRC Teaching Standard D: Learning environments. "Make available science tools, materials, media, and technological resources accessible to students."

NRC Program Standard C: "Science requires the use of mathematics in the collection and treatment of data and in the reasoning used to develop concepts, laws, and theories."

The NCTM Standards quote Henry Pollack (1987) on the mathematical expectations of new employees in industry.

"The ability to set up problems with the appropriate operations.
Knowledge of a variety of techniques to approach and work on problems.
Understanding of the underlying mathematical features of a problem.
The ability to work with others on problems.

The ability to see the applicability of mathematical ideas to common and complex problems.
Preparations for open problem situations, since most real problems are not well formulated.
Belief in the utility and value of mathematics."

How does HOU fit into these NRC and NCTM standards? The learning goals of HOU illustrate the match. There are four areas: Technology, Science, Math, and Student as Scientist and Learner.

Technology: The overall goal is not to learn about the technology for its own sake but to learn to use the technology as a tool for learning. Students learn to use the image processing software with its image manipulation and analysis tools and the data displays that are generated for image analysis. They also learn to use the telecommunications software to connect to the Internet and use the HOU homepage on the World Wide Web (WWW) to download images from the archive of images at telescopes, to request their own images, to share information, problems, and results with other HOU students, and to communicate with scientists associated with HOU as mentors.

Science: HOU integrates traditional science learning in the context of astronomy. Students use concepts about the kinematics and dynamics of orbital motion, gravity, energy, constancy and change, and properties of light - while learning about the moon, objects in our universe, and supernovae. Students collect and analyze data, apply critical thinking to investigations involving more than one parameter, and communicate their results and understanding to others.

Math: HOU integrates traditional math learning in the context of working with images and analyzing data. This includes: measurement, scaling, unit conversion, interpreting and plotting graphs, representation of data, transforming data between digital and graphical formats, 3D interpretation of 2D data, linear and log scaling, frequent use of ratios, and the use and formulation of equations. The *Measuring the Size of Moon Features Unit* includes using similar triangles and a proof of similarity.

Student as Scientist and Learner: The HOU materials strive to empower students to work collaboratively and to take control of their own learning. This means asking questions, collecting and analyzing data, making hypotheses, drawing conclusions by inductive and deductive reasoning, and communicating findings. In response to being asked "What is a scientist?" HOU students often reply "I am a scientist."

Astronomy Resource Materials List

1. Publications

- *Astronomy Magazine* - Monthly popular astronomy magazine - Kalmbach Publishing
- *CCD Astronomy* - Sky Publishing Corp
- *Mercury* - The Journal of the Astronomical Society of the Pacific, bi-monthly - ASP
- *NASA Report to Educators* - 4 times a year - NASA
- *Sky and Telescope* - Monthly popular astronomy magazine - Sky Publishing Corp
- *The Physics Teacher* - Monthly, September through May - AAPT
- *The Science Teacher* - Monthly, September through May -NSTA
- *The Universe in the Classroom* - Free newsletter for educators.
- Teachers' Newsletter Dept., ASP. The text is also available on the WWW at: http://www.physics.sfsu.edu/asp/asp.html

2. Organizations

AAPT - American Association of Physics Teachers

AAS - American Astronomical Society

ASP - Astronomical Society of the Pacific

IAU - International Astronomical Union

IDA - International Dark-Sky Association

NASA RTRCs - National Aeronautics and Space Administration Regional Teacher Resource Centers

NSTA - The National Science Teachers Association

STScI - Space Telescope Science Institute

TPS - The Planetary Society

"The Planetary Society exists to bring the results of planetary exploration to the public and to convince the nations of the world that it is an endeavor worth pursuing." excerpted from The Planetary Report; Vol. XV, Number 3, May/June 1995 - Charlene M. Anderson.

3. Observing Guides, Almanacs, Calendars

Burnham's Celestial Handbook by Robert Burnham, Jr.

Sky Publishing Corp, $14.95 each volume or all three for $40.00.

"This three-volume travelogue of the cosmos is a modern classic. Following an introduction for beginning observers are 2,138 descriptive pages on thousands of stars and deep sky-objects within reach of 2-inch or larger telescopes."

The Observers Handbook (yearly) - Sky Publishing, $16.95

The Royal Astronomical Society of Canada's annual handbook with 240 pages of essential celestial reference material. Monthly calendars of sky events, finder charts for outer planets, almanac data, plus many complementary articles.

Sky and Telescope Sky-Gazers Almanac (yearly)

Sky Publishing Corp, $2.95 (bulk discounts available)

Appears in the January issue of Sky and Telescope.

This is a colorful graphical chart from which one can determine a wide variety of celestial event times and dates. Find out when sunsets, oppositions, conjunctions, and meteor showers occur. Determine which planets are visible on any given date, etc. Large poster-size version available. Perfect for the classroom.

The Astronomical Calendar (yearly)

by Guy Ottewell, Sky Publishing, $16.95

"Ottewell's legendary Astronomical Calendar is a giant-size yearbook featuring day-by-day summaries of sky events and scads of helpful diagrams." 72 pages, 11 by 15 inches, paperbound.

The Astronomical Companion

by Guy Ottewell, Sky Publishing, $12.95

"A large format and unique, panoramic diagrams characterize this respected reference source. It's jammed with facts, figures, and lucid explanations about a wide variety of subjects, such as the Moon's orbit and eclipse seasons. A companion guide to Ottewell's annual *Astronomical Calendar*, it can also be enjoyed on its own." 72 pages, 11 by 15 inches, paperbound.

Moon Phase Poster (yearly) - Sky Publishing, $9.95

"This shimmering poster is a graphic and beautiful display of the celestial cycle that defines our month. Use it to track all of the Moon's phases through the year..." 16 by 37 inches, perfect for the classroom.

4. Atlases, Celestial Catalogs, Maps

Sky Atlas 2000.0 by Will Tirion - Sky Publishing, from $24.95

"The standard amateur's star atlas. Each edition contains 26 charts covering the whole sky." 43,000 stars, magnitude 8.0 and brighter. 2,500 identified deep-sky objects.

Sky Catalogue 2000.0, Vol. 1: Stars to Magnitude 8.0, 2nd edition by Alan Hirshfeld, Roger W. Sinnott, and Francois Ochsenbein - Sky Publishing, from $39.95. "In this massive tabulation you'll find the essential characteristics of more than 50,000 individual stars down to visual magnitude 8.0." See Sky Atlas 2000.0, its companion atlas.

Sky Catalogue 2000.0,Vol. 2: Double Stars, Variable Stars, and Nonstellar Objects Sky Publishing, from $39.95

Contains tables of data and notes of the essential characteristics of many astronomical objects.

Bright Star Atlas 2000.0 by Wil Tirion

"This affordable starter atlas has 10 maps covering the entire sky. 9,096 stars down to magnitude 6.5, a list of the brightest deep-sky wonders (600 in all) facing each map, and 6 seasonal constellation finder charts." Sky Publishing, $10.95

Norton's 2000.0 Star Atlas and Reference Handbook, 18th edition, edited by Ian Redpath - Sky Publishing or ASP, $47.95

"The 18 magnitude 6.5 star maps in this venerable work cover the entire sky. Each map is accompanied by tables of interesting objects and notes."

Moon Maps - Various maps available from Sky Publishing and others.

NGC 2000.0 edited by Roger Sinnott - Sky Publishing Corp, $19.95

"This updated and expanded edition of J. L. E. Dreyer's *New General Catalog* gives the coordinates and visual data for 13,226 nonstellar objects."

5. Bibliographies and Resource Lists

By Andrew Fraknoi

National Astronomy Education Projects: A Catalog - 1995

Astronomy Education in the U.S.: A Bibliography - V.1.3; 5/95

See also The Universe at Your Fingertips (see the next section)

6. Lab Manuals and Activity and Idea Books

Great Ideas for Teaching Astronomy - "Full of suggestions by some of the best astronomy teachers, written specifically for teachers." Recently updated. ASP, $14.95

Project STAR: The Universe in Your Hands - Text with Activities. Comprehensive teacher materials with Xerox masters and instructional videos. Kendall / Hunt Publishing Company

Project STAR - Activity Book: Where We Are in Space and Time -"21 hands-on activities in this 176-page spiral-bound book." Learning Technologies, Inc., $14.00

Project SPICA: A Teacher Resource to Enhance Astronomy

Ball, N., et al., eds. A collection of 43 astronomy activities at the 6th - 12th grade level. - Kendall / Hunt Publishing Company

Activities In Astronomy by Hoff, Kelsey, Neff: Nice upper level lab manual with sky maps and graph paper included. Kendall / Hunt Publishing Company

Sky Publishing ESSCO Classroom Charts and Laboratory Exercises

"These exercises are suitable for introductory classes in astronomy and for amateurs interested in learning the methods of the professional. Each exercise was prepared or approved by Owen Gingerich, Harvard-Smithsonian Center for Astrophysics. The Notes for Teachers with most of the exercises contain each author's results." Great variety. Inexpensive. Write or call them for a full listing of publications and prices. They will FAX the list.

The Universe at Your Fingertips: An Astronomy Activity and Reference Notebook - " An ideal source for everyone who teaches astronomy, this comprehensive collection of outstanding classroom activities, resource lists, and teaching ideas is a result of Project ASTRO, an ASP program sponsored by the National Science Foundation to bring astronomers and teachers together as partners in the classroom. ed. by Andrew Fraknoi, et al. - 7/95 - ASP, $24.95

7. Catalogs and Sources for Astronomy Teaching Materials

ASP - Astronomical Society of the Pacific

LTI - Learning Technologies, Inc. - Project STAR, Star LAB

Sky Publishing Corp

Willmann-Bell, Inc.

Most distributors of science education equipment have an Earth Science or Astronomy section that contains a wide variety of materials for teaching astronomy. Examples of such distributors are Sargent Welch, Frey Scientific, Science Kit.

NASA - Free materials for educators

STScI - Free materials for educators

8. Videos, Laser Disks and CD-ROMs - A listing of some of the more familiar and popular items. See the various catalogs for more listings.

Laser Disks

Voyager Gallery - "This complete multimedia record of the Voyager to Jupiter, Saturn, and Uranus contains 2700 photographs and 36 movie clips." ASP, $195.00

Planetscapes - " An exhaustive compilation of over 100,000 frames of photographs, animations, and films about Mercury, Venus, Mars, and Earth." ASP, $195.00

CD-ROMs

Hubble Space Telescope Guide Star Catalog - ASP, $69.95

NSSDC - National Space Science Data Center - a very large assortment of image and data CD-ROMs available. See the URL listed below under WWW.

HOU Explorer CD-ROM - A virtual observatory environment. Students are presented with astronomical missions that require aiming a virtual telescope, capturing an image, and doing virtual image processing with simulated, simplified version of HOU Image Processing software. As missions are completed, students acquire pieces of a giant telescope that they can assemble as a culminating activity.

Video Tapes

The Astronomers - PBS series

A Private Universe - "The tape should be seen by all teachers." -Andrew Ahlgren, AAAS. Contains many examples of common misconceptions about the reasons for the seasons directly from videotaped answers from a wide variety of "educated people". Surprising results. ASP - $39.95

9. Computer Programs - Listed here are some of the more popular commercial versions. For the best prices, check some of the computer warehouse outlets (mail order, as well) as many of them are now carrying these popular programs. There is much shareware available, as well. Ask around.

MAC

Voyager II, the Dynamic Sky Simulator - ASP, from $159.95

Redshift - Sky Publishing, $59.00

Distant Suns - Virtual Reality Laboratories, Inc.

PC

The Sky Astronomy Software for Windows- ASP, from $199.95

Dance of the Planets

PC-Sky - Sky Publishing, $99.00

10. World Wide Web (WWW)

AAS - American Astronomical Society.
http://blackhole.aas.org/AAS-homepage.html

ASP - Astronomical Society of the Pacific. ASP information, activities and publications. http://www.aspsky.org/
Project Astro of the Astronomical Society of the Pacific (ASP) links professional and amateur astronomers with teachers in their communities. Though as of year 2000, their focus is mainly 4th - 9th grade, the concept is applicable for enhancement of HOU activity. Project Astro webpage is at
http://www.aspsky.org/project_astro.html

Gettysburg College Project - CLEA. Information on astronomical laboratory exercises.
http://www.gettysberg.edu/project/physics/clea/CLEAhome.html

University of Arizona SEDS. Large quantity of astronomical images and information. http://seds.lpl.arizona.edu

WebStars. Guide to astrophysics on the WWW.
http://guinan.gfsc.nasa.gov

The Space Science Education Resource Directory. Provides educators an entry point into the wealth of education materials funded by NASA's Office of Space Science Education and Public Outreach Program. http://teachspacescience.stsci.edu

Satellite locations from any point on earth
http://www.heavens-above.com

Free monthly evening sky maps -- http://www.skymaps.com

A complete on-line astronomy text book.
http://www.astronomica.org/textbook/

Star Gazing tips (humorous).
http://www.theonion.com/onion3706/stargazing_tips.html

The NASA Astrophysics Data System -- http://adsabs.harvard.edu/
Real research implies finding articles in journals that provide results and findings pertinent to a given research project. This Astrophysics Data System is an excellent search system for Astrophysics, Planetary Sciences, and Solar Physics Abstracts. The following system also includes whole articles:
http://xxx.lanl.gov/find/astro-ph

Reference Images:

STScI Digitized Sky Survey to get RA and Dec of objects as well as reference .fit images http://stdatu.stsci.edu/cgi-bin/dss_form

SkyView is a Virtual Observatory on the Net generating images of any part of the sky at wavelengths in all regimes from Radio to Gamma-Ray. http://skyview.gsfc.nasa.gov/

SkyView is great to get images, find coordinates, and be overwhelmed. Problems with 32 bit fits and other issues that make it somewhat tricky to work with.

How to put in a request to skyview for a comparison image:
Go to SkyView Virtual Observatory
http://skyview.gsfc.nasa.gov/skyview.html
Choose Advanced.
Put in coordinates for an object (such as m106).
Select Digitized Sky Survey.
In the Optional Parameters choose Brightness Scaling: Linear
Color Table: B-W Linear
Image Scale: 0.3 (will give more than enough stars to compare to the images).
Hit Submit.
In a separate browser window, you get a jpeg of the sky. You can download a fts or a gif image. You can print out the chart as a finder (field of view can be about 5 arcminutes by 5 arcminutes). There are also instructions on how to use skyview in the lesson for sscyg at http://hou.lbl.gov/~vhoette/Explorations/SSCyg

NASA Sites:

NSSDC - National Space Science Data Center - The National Space Science Data Center provides on-line access via the World Wide Web (WWW) and other pathways as well as off-line access to a wide variety of astrophysics, space plasma and solar physics, and lunar and planetary data from NASA space flight missions in addition to selected other data and some models and software. http://nssdc.gsfc.nasa.gov/nssdc/nsssdc_home.html

ADC - Astronomical Data Center at NASA/Goddard Space Flight Center. The basic function of the ACD is to be a repository of high quality data." There is more information and data here than you could use in ten lifetimes. For more information take a look at their home page. http:/nssdc.gsfc.nasa.gov/adc/aadc.html

Overview of NASA information. http://www.gfsc.nasa.gov -- NASA Goddard Space flight Center.

Daily News about Sun-Earth Environment http://spaceweather.com/

Daily updates from NASA http://science.nasa.gov/Astronomy.htm

Astronomy Picture of the Day. http://antwrp.gsfc.nasa.gov/apod/ (Also the archive of previous "pictures of the day").

STScI - Space Telescope Science Institute. Institute information, programs and Hubble images. http://marvel.stsci.edu
NASA scientists are jubilant about the quality of images from the newly refurbished HST. You might enjoy a look at these URLs: http://oposite.stsci.edu/pubinfo/pr/2000/07

http://oposite.stsci.edu/pubinfo/pr/2000/08 and via links in
http://oposite.stsci.edu/pubinfo/latest.html and
http://oposite.stsci.edu/pubinfo/pictures.html

More astronomy websites may be found at
http://www.lhs.berkeley.edu/SII/URLs/URLs-Astronomy.html
and NASA websites at
http://www.lhs.berkeley.edu/SII/URLs/WhatsNASA.html

Telescope networking:

The HOU Global Telescope Network is under development, but you and your students can also acquire images by the following strategies as well:

Get in touch with your nearest Astronomy Club and seek out members who do CCD imaging and are interested in collaborating with your school. A complete listing of Astronomy Clubs may be found at the Sky And Telescope magazine website -- http://www.skypub.com/resources/directory/directory.shtml

The Micro Observatory project aims to network together several remote telescopes for use by students from grades 4-12. They are creating specialized software that will allow students to work with each other and to collaborate with astronomers on research projects. The MicroObservatory web site is at http://mo-www.harvard.edu/MicroObservatory/

The Telescopes in Education (TIE) project at Mt. Wilson Observatory operate a remotely controlled 24-inch telescope and CCD camera in real time on Mt. Wilson. Website is http://tie.jpl.nasa.gov/tie/index.html

11. Text and Reference Books

<u>Astronomy and Astrophysics Encyclopedia</u>
edited by Stephen P. Maran, 1992
Van Nostrand Reinhold Publishing, NY

<u>Exploration of the Universe</u>
by Abell, Morrison, Wolff ; 6th ed., 1993
Saunders College Publishing

<u>Introductory Astronomy and Astrophysics</u>
by Zeilik, Gregory, Smith; 3rd ed., 1992
Saunders College Publishing

<u>The Evolving Universe</u>
by Michael Zeilik; 7th ed., 1994
John Wiley and Sons, Inc.

<u>Conceptual Astronomy</u>
by Michael Zeilik; 1993
John Wiley and Sons, Inc.

<u>Astronomy - From Earth to Universe</u>
by Jay M. Pasachoff (Williams); 4th ed., 1993 Version
Saunders College Publishing

The Physical Universe - Introduction to Astronomy
by Frank Shu (Berkeley)
University Science Books; 1982
Mill Valley, CA
An excellent upper level undergraduate calculus-based astrophysics text. A good reference for teacher background material.

Astronomy Today
By Eric Chaisson (Tufts) and Steve McMillan (Drexel)
Prentice Hall; 1993
Englewood Cliffs, NJ

Astronomy !
by James Kaler (U. Illinois, Urbana-Champaign)
Harper Collins College Publishers; 1994
Introductory text with good information on star color.

12. General Reading - Some are keyed to certain HOU themes

The Super-Nova Story - "Here is the full and spectacular story of the brilliant supernova of 1987 and the supernovae that preceded it." - Relevant to Supernova work. By Larry A. Marschall, 1988 Plenum Press

Lonely Hearts of the Cosmos - "... Overbye's dramatic, heartbreaking, and often comical story of cosmology and the men and women devoted to discovering the secrets of the Universe." by Dennis Overbye, 1992 Harper Perennial

13. Publishers

Kalmbach Publishing Co.
21027 Crossroads Circle
P.O. Box 1612
Waukesha, WI 53187
(800) 446-5489: customer service

Kendall / Hunt Publishing Company
2460 Kerper Boulevard
P.O. Box 539
Dubuque, Iowa 52004-0539
(800) 228-0810

Sky Publishing Corporation
P.O. Box 9111
Belmont, MA 02178-9111
(800) 253-0245: Catalog sales

WEST Publishing Co.
50 W. Kellog Boulevard
P.O. Box 64526
St. Paul, MN 55164-1003

Willman-Bell, Inc.

P.O. Box 35025
Richmond, Virginia 23235
(804) 320-7016
(804) 272-5920 FAX

14. Addresses

AAPT - American Association of Physics Teachers
One Physics Ellipse
College Park, MD 20740-3845

AAS - American Astronomical Society
Education Office (Mary K. Hemenway, Education Officer)
University of Texas
Dept. of Astronomy
Austin, TX 78712-1083
e-mail: aas@astro.as.utexas.edu

ASP - Astronomical Society of the Pacific
390 Ashton Ave.
San Francisco, CA 94112

IDA - International Dark-Sky Association
3545 N. Stewart
Tucson, AZ 85716

LTI - Learning Technologies, Inc.
59 Walden Street
Cambridge, MA 02140 (800) 537-8703

NASA RTRCs - To get the name and address of the regional TRC nearest you, try contacting:
Goddard Space Flight Center
Mail Code 130.3
Greenbelt, MD 20771 (301) 286-8570

NSTA - The National Science Teachers Association
1840 Wilson Boulevard
Arlington, VA 22201-3000
(703) 243-7100

Sargent Welch Scientific Company
911 Commerce Court
Buffalo Grove, IL 60089-2362
(800) SARGENT

TPS - The Planetary Society
65 N. Catalina Ave.
Pasadena, CA 91106-2301
e-mail: TPS@genie.geis.com
WWW Homepage - http://wea.mankato.mn.us/TPS/

Virtual Reality Laboratories, Inc.
2341 Ganador Court
San Luis Obispo, CA 93401-9826 (805) 545-8515

Tables and Diagrams

A. Messier Catalog

Charles Messier was an astronomer in the late 18th century who was searching for comets. In his observations he was constantly fooled by nebulous objects of various sorts, so he made a catalog of "fuzzy" objects visible in the Northern Hemisphere that are not comets. His catalog has now become a standard tool of most amateur astronomers and the Messier numbers are frequently used to refer to many of the most beautiful galaxies and nebulosity in our night sky. The Messier Catalog is included in the Finding Features Theme; however, it is good to post a copy for referral at other times.

B. The HOU Brightness Conversion Table

When describing the brightness of an object, particularly a star, astronomers often give the magnitude of the star. The magnitude scale is unitless, logarithmic and inverse. The fact that it is unitless alleviates many of the stumbling blocks students have when dealing with a quantity such as brightness which is measured in Watts/m^2, the fact that the scale is logarithmic instead of linear confuses many students, and the fact that it is inverse makes even the most expert astronomer have to think twice.

The magnitude scale is described in detail, with activities provided, in the HOU Theme on Measuring Brightness. In these activities and other places in the HOU curriculum, the brightness of a star is given in magnitude, since this is what one would commonly find in any other reference material. For those students who are not doing the HOU activities on magnitudes, we have provided a Brightness Conversion Table to find the brightness (in Watts/m^2) from the magnitude. In general, one knows the magnitude of a star as seen through a specific filter. This chart can be used to find the brightness of the star through that filter. The magnitude to brightness (or reverse) conversions are applicable for both apparent and absolute magnitudes as long as one is consistent about which is being used.

C. The HR Diagram

The Hertzsprung-Russell Diagram is extremely useful in the classification of stars. The HOU Measuring Color Book explains its use. The diagram provided here is a general HR diagram representing a large sample of stars.

D. The Period-Luminosity Diagram for Classical Cepheids

Cepheid variable stars fluctuate periodically in brightness, usually over the course of days. The brightness fluctuation is caused by the pulsation of the star which changes the temperature and the radius of the star periodically. Since the luminosity is dependent on both temperature and radius, the pulsation causes a fluctuation in the brightness. Cepheid variable stars can be used as standard candles for measuring distance to star clusters and other galaxies because of the direct relationship between their period of fluctuation and their luminosity. The brightest Cepheids (highest luminosity) have the longest periods while the dimmer ones have shorter periods. One can remember this by thinking that stars with a larger radius have a longer pulsation path, meaning it takes longer to change between the minimum radius and maximum radius, so they have the longest period. Larger radius stars will typically have greater mass and thus greater luminosity as well. A cautionary note however: the physics of Cepheids is far more complex than this, having to do with various modes of heat transfer and an instability of the position of the convection layer of the star.

The HOU Cepheid Variable Stars Unit in the Measuring Distance Book goes through the technique of plotting a light curve of a Cepheid to measure the period of fluctuation. From the period the luminosity is obtained using the Period-Luminosity Diagram, and having measured the apparent brightness of the star, its distance can be calculated.

Messier Catalog

Key to Column Headings: M# is Messier number, NGC# is the New General Catalog number, Type is the type of object as identified below, RA is Right Ascension, Dec is Declination, Con is Constellation that the object is found in, and m(v) is the apparent magnitude through a v filter.

Key to Types: OC = Open Cluster, GC = Galactic Cluster, SNR = Supernova Remnant, PN = Planetary Nebula, EN = Emission Nebula, RN = Reflection Nebula, SG = Spiral Galaxy, EG = Elliptical Galaxy, DS = Double Star

M#	NGC #	Type	RA	Dec	Con	m(v)	remarks
M1	1952	SNR	05h34.5m	+22°01'	Tau	8.4	Crab Nebula
M2	7089	GC	21h33.5m	–00°49'	Aqr	6.5	
M3	5272	GC	13h42.2m	+28°23'	CVn	6.4	Contains variables
M4	6121	GC	16h23.6m	–26°32'	Sco	5.9	Bright globular
M5	5904	GC	15h18.6m	+02°05'	Ser	5.8	Beautiful globular
M6	6405	OC	17h40.1m	–32°13'	Sco	4.2	Butterfly Cluster
M7	6475	OC	17h53.9m	–34°49'	Sco	3.3	good in binoculars
M8	6523	EN	18h03.8m	–24°23'	Sgr	5.8	Lagoon Nebula
M9	6333	GC	17h19.2m	–18°31'	Oph	7.9	
M10	6254	GC	16h57.1m	–04°06'	Tau	6.6	
M11	6705	OC	18h51.1m	–06°16'	Sct	5.8	Wild Duck Cluster
M12	6218	GC	16h47.2m	–01°57'	Oph	6.6	
M13	6205	GC	16h41.7m	+36°28'	Her	5.9	Hercules Cluster
M14	6402	GC	17h37.6m	–03°15'	Oph	7.6	
M15	7078	GC	21h30.0m	+12°10'	Peg	6.4	
M16	6611	EN+OC	18h18.8m	–13°47'	Ser	6.0	Eagle Nebula with OC
M17	6618	EN	18h20.8m	–16°11'	Sgr	7.0	Swan or Omega Neb.
M18	6613	OC	18h19.9m	–17°08'	Sgr	6.9	
M19	6273	GC	17h02.6m	–26°16'	Oph	7.2	
M20	6514	E/RN	18h02.6m	–23°02'	Sgr	8.5	
M21	6531	OC	18h04.6m	–22°30'	Sgr	5.9	
M22	6656	GC	18h36.4m	–23°54'	Sgr	5.1	
M23	6494	OC	17h56.8m	–19°01'	Sgr	5.5	
M24			18h16.9m	+18°29'	Sgr	4.5	Rich star cloud
M25	IC4725	OC	18h31.6m	–19°15'	Sgr	4.6	
M26	6694	OC	18h45.2m	–09°24'	Sct	8.0	
M27	6853	PN	19h59.6m	+22°43'	Vul	8.1	Dumbbell Nebula
M28	6626	GC	18h24.5m	–24°52'	Sgr	6.9	
M29	6913	OC	20h23.9m	+48°26'	Cyg	6.6	
M30	7099	GC	21h40.4m	–23°11'	Cap	7.5	
M31	224	SG	00h42.7m	+41°16'	And	3.4	Andromeda Galaxy
M32	221	EG	00h42.7m	+40°52'	And	8.2	companion to M31
M33	598	SG	01h33.9m	+30°39'	Tri	5.7	
M34	1039	OC	02h42.0m	+42°47'	Per	5.2	
M35	2168	OC	06h08.9m	+24°20'	Gem	5.1	

M36	1960	OC	05h36.1m	+34°08'	Aur	6.0	
M37	2099	OC	05h52.4m	+32°33'	Aur	5.6	
M38	1912	OC	05h28.7m	+35°50'	Aur	6.4	
M39	7092	OC	21h32.2m	+48°26'	Cyg	4.6	
M40		DS	12h22.4m	+58°05'	UMa	8.0	
M41	2287	OC	06h47.0m	–20°01'	CMa	4.5	
M42	1976	EN	05h35.4m	–05°27'	Ori	4.0	Orion Nebula
M43	1982	EN	05h35.6m	–05°16'	Ori	9.0	part of Orion Nebula
M#	NGC #	Type	RA	Dec	Con	m(v)	remarks
M44	2632	GC	08h40.1m	+19°59'	Cnc	3.1	Beehive Cluster
M45	1952	OC	03h47.0m	+24°07'	Tau	1.2	Pleiades
M46	2437	OC	07h41.8m	-14°49'	Pup	6.1	
M47	2422	OC	07h36.6m	–4°30'	Pup	4.4	
M48	2548	OC	08h13.8m	–05°48'	Hya	5.8	
M49	4472	EG	12h29.8m	+08.00'	Vir	8.4	
M50	2323	OC	07h03.2m	–08°20'	Mon	5.9	
M51	5194	SG	13h29.9m	+47°12'	CVn	8.1	Whirlpool Galaxy
M52	7654	OC	23h24.2m	+61°35'	Cas	6.9	
M53	5024	GC	13h12.9m	+18°10'	Com	7.7	
M54	6715	GC	18h55.1m	–30°29'	Sgr	7.7	
M55	6809	GC	19h40.0m	–30°58'	Sgr	7.0	
M56	6779	GC	19h16.6m	+30°11'	Lyr	8.2	
M57	6720	PN	18h53.6m	+33°02'	Lyr	9.0	Ring Nebula
M58	4579	SG	12h37.7m	+11°49'	Vir	9.8	
M59	4621	EG	12h42.0m	+11°39'	Vir	9.8	
M60	4649	EG	12h43.7m	+11°33'	Vir	8.8	
M61	4303	SG	12h21.9m	+04°28'	Vir	9.7	face-on spiral
M62	6266	GC	17h01.2m	–30°07'	Oph	6.6	
M63	5055	SG	13h58.8m	+42°02'	CVn	8.6	Sunflower Galaxy
M64	4826	SG	12h56.7m	+21°41'	Com	8.5	Black-eye Galaxy
M65	3623	SG	11h18.9m	+13°05'	Leo	9.3	
M66	3627	SG	11h20.2m	+12°59'	Leo	9.0	
M67	2682	OC	08h50.4m	+11°49'	Cnc	6.9	
M68	4590	GC	12h39.5m	–26°45'	Hya	8.2	
M69	6637	GC	18h31.4m	–32°21'	Sgr	7.7	
M70	6681	GC	18h43.2m	–32°18'	Sgr	8.1	
M71	6838	GC	19h53.8m	+18°47'	Sge	4.4	
M72	6981	GC	20h53.5m	–12°32'	Aqr	9.4	
M73	6994	OC	20h58.9m	–12°38'	Aqr	4.4	
M74	628	SG	01h36.7m	+15°47'	Psc	9.2	
M75	6864	GC	20h06.1m	-21°55'	Sgr	8.6	
M76	650	PN	01h42.4m	+51°34'	Per	11.5	Little Dumbbell
M77	1068	SG	02h42.7m	–00°01'	Cet	8.8	a Seyfert Galaxy
M78	2068	RN	05h46.7m	+00°03'	Pup	8	
M79	1904	GC	05h24.5m	–24°33'	Lep	8.0	
M80	6093	GC	16h17.0m	–22°59'	Sco	7.2	

M81	3031	SG	09h55.6m	+69°04'	UMa	6.8	
M82	3034	SG	09h55.8m	+69°41'	UMa	8.4	the 'exploding' galaxy
M83	5236	SG	13h37.0m	–29°52'	Hya	10.1	
M84	4374	EG	12h25.1m	+12°53'	Vir	9.3	
M85	4382	EG	12h25.4m	+18°11'	Com	9.3	
M86	4406	EG	12h26.2m	+12°57'	Vir	9.2	
M87	4486	EG	12h30.8m	+12°24'	Vir	8.6	visible jet
M88	4501	SG	12h32.0m	+14°25'	Com	9.5	
M89	4552	EG	12h35.7m	+12°33'	Vir	9.8	
M90	4569	SG	12h36.8m	+13°10'	Vir	9.5	
M91	error in Messier catalog						
M92	6341	GC	17h17.1m	+43°08'	Her	6.5	
M93	2447	OC	07h44.6m	–23°52'	Pup	6.2	
M94	4736	SG	12h50.9m	+41°07'	CVn	8.1	
M95	3351	SG	10h44.0m	+11°42'	Leo	9.7	
M96	3368	SG	10h46.8m	+11°49'	Leo	9.2	

M#	NGC #	Type	RA	Dec	Con	m(v)	remarks
M97	3587	PN	11h14.8m	+55°01'	UMa	11.2	Owl Nebula
M98	4192	SG	12h13.8m	+14°54'	Com	10.1	nearly edge-on
M99	4254	SG	12h18.8m	+14°25'	Com	9.8	nearly face-on
M100	4321	SG	12h22.9m	+15°49'	Com	9.4	face-on
M101	5457	SG	14h03.2m	+54°21'	UMa	7.7	Pinwheel Galaxy
M102	error in Messier catalog						
M103	581	OC	01h33.2m	+60°42'	Cas	7.4	
M104	4594	SG	12h40.0m	–11°37'	Vir	8.3	Sombrero Galaxy
M105	3379	EG	10h47.8m	+12°35'	Leo	9.3	
M106	4258	SG	12h19.0m	+47°18'	CVn	8.3	
M107	6171	GC	16h32.5m	–13°03'	Oph	8.1	
M108	3556	SG	11h11.5m	+55°40'	UMa	10.0	nearly edge-on
M109	3992	SG	11h57.6m	+53°23'	UMa	9.8	
M110	205	EG	00h40.5m	+41°41'	And	8.0	

Brightness Conversion Table

Magnitude to Brightness (W/m²)

[redacted]

5.49

Mag. 6.1

Bolometric Filters Various

Brightness Conversion Table

Magnitude to Brightness (W/m^2)

Mag. 8 8 8 8 8 8 8 8 8 9 9 9 9 9 9 9 9 9 9 10

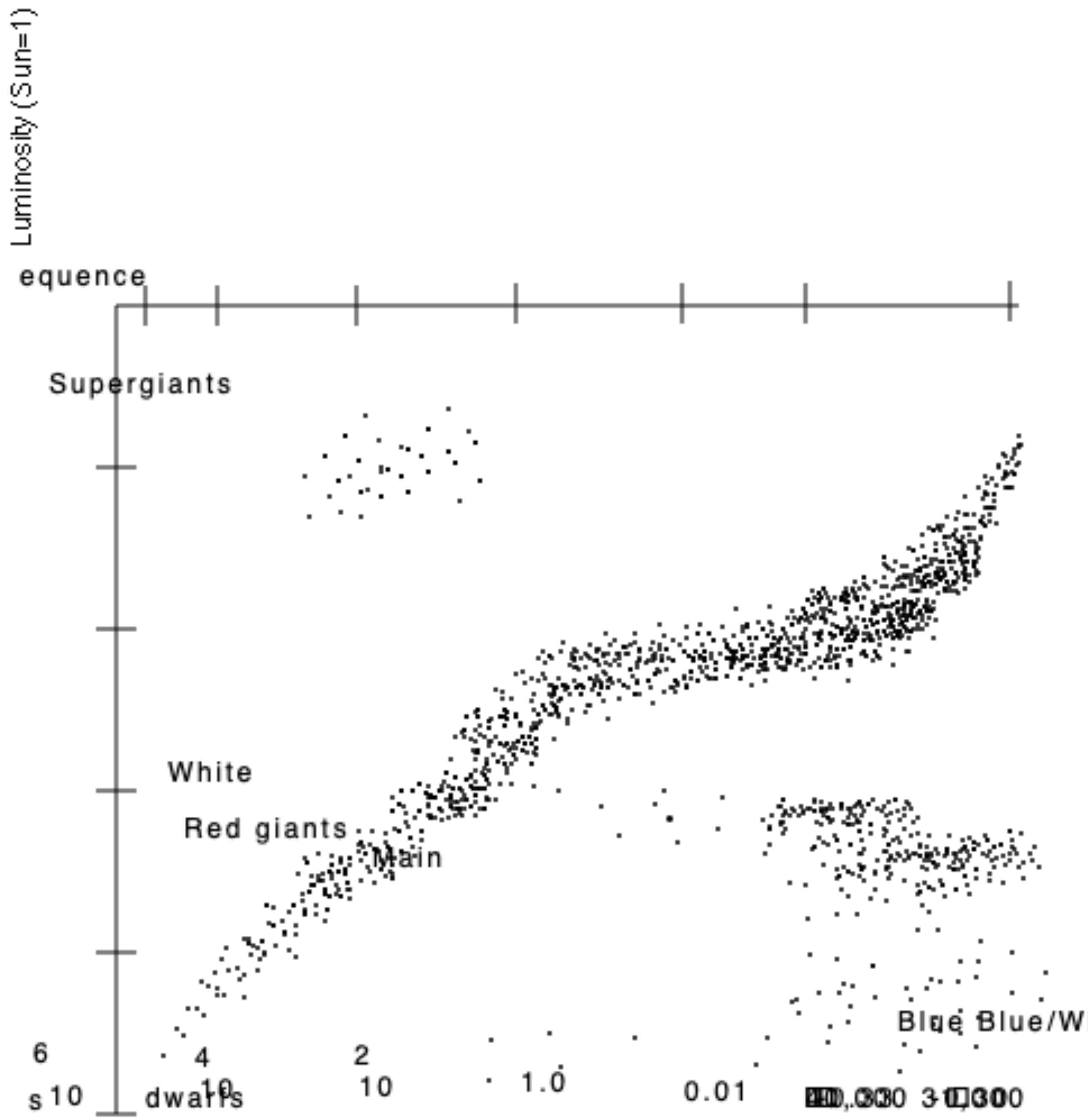
Bolometric

Key: I = Infrared; R = Red; V = Yellow of Visual; B = Blue;

U = Ultraviolet;

Bolometric is total brightness over all wave lengths.

Hertzsprung-Russell Diagram



Period-Luminsoity Diagram for Classical Cepheids

Period-Luminosity Diagram for Classical Cepheid Variable Stars

HANDS-ON UNIVERSE™
Constants Sheet

Planetary Data:

Planet	**Mass (kg)**	**Ave Radius (m)**	**Ave Orbital Radius(m)**
Mercury	3.32×10^{23}	2.44×10^{6}	5.79×10^{10}
Venus	4.87×10^{24}	6.08×10^{6}	1.08×10^{11}
Earth	5.97×10^{24}	6.36×10^{6}	1.49×10^{11}
(Moon)	7.35×10^{22}	1.74×10^{6}	
Mars	6.42×10^{23}	3.40×10^{6}	2.28×10^{11}
Jupiter	1.90×10^{27}	6.80×10^{7}	7.78×10^{11}
Saturn	5.69×10^{26}	5.70×10^{7}	1.43×10^{12}
Uranus	8.69×10^{25}	2.51×10^{7}	2.87×10^{12}
Neptune	1.03×10^{26}	2.44×10^{6}	4.50×10^{12}
Pluto	1.30×10^{22}	1.50×10^{6}	5.90×10^{12}

Physical and Astronomical Constants:

Gravitational Constant = G = 6.673×10^{-11} N-m^2/kg^2

Velocity of Light in a vacuum = c = 2.9979×10^{8} m/s

Earth-Sun Distance = Astronomical Unit = AU = 1.496×10^{11} m

Parsec = pc = 206265 AU = 3.26 ly = 3.09×10^{16} m

Light year = ly = 9.46×10^{-15} m

Mass of the Sun = 1.989×10^{30} kg

Luminosity of the Sun = 3.83×10^{26} W

Radius of the Sun = 6.96×10^{8} m

