**Student Observation Driven Astronomy (SODA) across the ACS**
**Final Report 08/09/10**

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**Co Investigators:**
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Sarah Doty and Jennifer Heaton (Southwestern University)
Gareth Jones (Trinity University)
Ryan Strickland (Hendrix College)
and two additional students at The College of the South

**Acknowledgements:** This project was generously funded by the Mellon Foundation. The participants are very grateful to the Mellon Foundation for providing the financial support for this project. The project was administered by the Associated Colleges of the South (ACS). The PI would like to personally thank Marcia White at the ACS for her guidance and flexibility when it proved difficult to meet the original timeline. It allowed this project to come to successful fruition.

**Results of the Grant:** The end product of this grant is a collection of seven astronomy labs and three tutorials (these from Sewanee: The University of the South) and are meant to be shared across all ACS colleges. The labs conform to the SODA grant requirements that: (1) their structure be useable to students at ACS (or other) institutions that do not necessarily have observatory facilities, lab equipment or astronomical viewing conditions to carry out astronomical observations, and (2) the labs enable students to determine basic 'meat and potatoes' facts about the universe from their own data or data obtained by other students at ACS institutions. The majority of the data, in these labs, was acquired by ACS students, using ACS observatory or science laboratory facilities or from the SOHO (Solar and Heliospheric Observatory) space satellite public data archive or from the public access astronomy website for the Sloan Digital Sky Survey. The remainder of the initial data was acquired by professors at ACS institutions using small telescope instrumentation. ACS students will supplant professor acquired data when they carry out observations (or web data searches) for themselves in future ACS astronomy classes. The Sewanee tutorials center on using software called Astrometrica™. Technically, not all ACS institutions would be expected to have this software. However: (1) the software is inexpensive, (2) Sewanee has provided a wealth of astronomical image data of comets and asteroids (representing many person-hours of effort) that can be utilized and (3) one of the tutorials (on measuring comets) has had an alternative procedure added to it so it too can be worked as a lab activity without the software.

All of the labs have augmented or added introductions. The idea being that the general subject background for each lab is established in the lab document. Therefore (if need be) the labs can be used as a stand alone learning experience. The intent is not (necessarily) to make a textbook obsolete but rather to close the gap between material covered in a standard astronomy text book and the laboratory work carried out by students. In both labs and tutorials astronomical vocabulary terms appear underlined or in boldface (at their first occurrence) and a vocabulary list is provided near the end of each document. In addition worked computational examples are presented in the labs (and one tutorial) to assist students in carrying out numerical calculations. A small battery of (basic) questions: true false, multiple choice, fill in the blank and quantitative reasoning questions appear at the end of the labs to help ensure that the student has gone through the introductory sections. Students will therefore have a bigger picture of the topic beyond the limited scope of a lab, which usually focuses on only one aspect of a topic. For example an introductory section and the questions corresponding to it might be on the Sun's internal structure and visible features whereas the actual lab might be about sunspots (a *particular* visible feature caused by the interior magnetic structure of the Sun) and their use to determine the differential rotation rate of the Sun (which in turn tells us something about the interior structure of the Sun). Hopefully this approach establishes context and helps avoid labs being gone through in a purely formulaic manner by students. Conversations with education consultant Dr. Michael Kamen (SU), about some of the SODA lab contributions, have guided the PI in the editorial transformation of all the contributed lab materials into SODA labs.

The materials fill 198 pages, including figures and graphs. In addition 366 megabytes of astronomical images, provided by The University of the South, are included. These materials all conveniently fit onto a single CD. They have recently been shipped to the non SU grant participants for review and comment. An addition a copy has been sent to Marcia White at the ACS home office for the ACS files and as proof of product delivery. After the PI receives feedback, suggested changes or minor corrections that enhance the labs will be made. Following this, additional copies will be shipped out to ACS colleges on request. What follows is: (1) a review of the CD contents, (2) a description of the utilization of SU SODA grant resources, (3) Individual grant reports by non-SU SODA grant participants.

**1. Review of the SODA CD Contents:** The CD contains: (1). A README.txt file that essentialy contains the information presented below, (2) a folder called 'Final_SODA_Labs', (3) A folder called 'Original_SODA_Labs', and (4) A folder called 'ProImages'. The contents of these folders are described in some detail below:

**The Final_SODA_Labs Folder:** The Final_SODA_Labs folder contains final edited, rewritten or otherwise augmented drafts of contributions to the Student Observation Driven Astronomy (SODA) project. The seven labs and activities (hereafter referred to as generically as 'labs') and the three tutorials are in pdf format. Descriptions of the labs and tutorials follow:

**Labs:**

1. Final_Crater_SU.pdf: (26 pages) This lab is an 'indoor' experience. Students study the physics of impact crater formation, an important process in early in the history of the solar system. Steel ball bearings of different mass are dropped from different heights into a bed of sand and the size of the resulting crater is measured. Different theories about how craters form are tested by plotting the relationship of ball bearing times drop height (a proxy for the kinetic energy of the imactor) and crater diameter. One of the important lessons learned in this lab is that the scientific process does not prove theories true but rather falsifies incorrect theories by comparing empirical data to the predictions of theory.

2. Final_DoubleStar_SU.pdf (20 pages) In this lab a multiple image of the double star eta Cassiopeia, taken with a small telescope, is measured. The angular separation and position angle (the angle east of due north) of the system is determined and the student determined position is compared to historical data. A result is that the students see that the double star system rotates (albeit slowly). Students learn the basic physics of double stars and that that much of what we know about stars came from the careful study of double stars carried out by generations of dedicated astronomers.

3. Final_Exoplanet_Trinity.pdf (22 pages) A student at Trinity University used a CCD camera attached to the Trinity University observatory 16 inch Schmidt Cassegrain telescope to record the change in brightness of a star due to an exoplanet transiting across the face of the star. Only the brightening of the star was recorded as the planet exited transit; however the data, combined with other archival data, is sufficient make many interesting inferences about the nature of the exoplanet. Within this lab the basic physics of exoplanet detection by the transit method is developed as well as how inferential science is used to learn things about objects that can not be directly seen.

4. Final_Lunar_Trinity.pdf (27 pages) The dimensions of lunar features are studied in this lab. Two images are provided for analysis. One is taken through the 16 inch Schmidt Cassegrain telescope at the Fountainwood Observatory on the Southwestern University campus. The other is taken through a small telescope by an introductory astronomy student at Southwestern University during the Spring 2010 semester. The diameters of crater features are carefully measured and the heights of lunar features are estimated based on the length of the shadows they cast.

5. Final_Spectroscopy_Hendrix.pdf (39 pages) In this extensive lab activity, the basic ideas of how spectroscopy is used to deduce the chemical composition of astronomical objects is laid out. After a lengthy discussion of the wave and particle nature of light, a diffraction experiment, using monochromatic laser light, is analyzed to investigate the wave properties of monochromatic light and how a diffraction grating can be used to separate light into its (color) components for analysis. Spectral data from a variety of emission line tubes, measured with a high quality diffraction grating student spectrograph, is presented (or if a spectrograph is available students can obtain their own data) and the emission line wavelengths are computed. Students are then presented with spectra of stars and galaxies obtained from the data archives of the Sloan Digital Sky Survey. They use their own spectrographic data to identify the presence of hydrogen and attempt to deduce the presence of other elements in the astronomical spectra.

6. Final_Sun_Hendrix.pdf (19 pages) In this lab students measure the rotation rate of the Sun using archival SOHO data. By measuring the motion of sunspots appearing at different latitudes on the solar disk the differential rotation of the Sun is deduced, demonstrating that the Sun does not rotate as a solid body.

7. Final_Variable_SU.pdf (17 pages) Periodic variable stars are important distance indicators in astronomy. In this lab, the light curves of three different periodic variable stars, all occurring in the same star cluster, are plotted. The students deduce the type of periodic variable star each one is. Once this is done the period of the variable star is measured and the intrinsic brightness of the star is deduced from a period-luminosity relationship. By comparing the intrinsic luminosity to the apparent luminosity and assuming that the light from the variable stars disperse into space in inverse proportion to the square of the distance from each one, the distance from Earth to each star is deduced. The distances are then averaged to give the distance to the cluster.

**Tutorials:**

1. Final_Asteroid Astrometery_Sewanee.pdf (6 pages) This document is a tutorial “to introduce students to the software (Astometrica$^{TM}$) used to measure the positions of objects in the sky (astrometry) and to see how asteroids are discovered.”

2. Final_Comet Size_Sewanee.pdf (16 pages) This document has the student go through the details of using Astometrica$^{TM}$ to measure the angular size of the various parts of a comet. The physical sizes of the parts are then inferred based on the known distance of the comet at the time the image was taken. In the Alternative Procedure an image of a comet is measured (either off a hardcopy print out or off a computer screen) simply using a ruler. Given the known effective focal length of the telescope and the physical size of the CCD chip in the camera used to take the image the angular extent of each comet component is deduced and from this the projected linear dimensions of the various parts of the comet inferred.

3. Final_Image Processing_Sewanee.pdf (6 pages) This document consists of helpful hints for taking high quality astronomical images and using Astrometrica$^{TM}$ to calibrate the image relative to the positions of known stars in the US Naval Observatory CCD Astrometric Catalogue (UCAC 2).

**The Original_SODA_Labs Folder:**

This folder contains four folders: (1) Original Labs_Hendrix, (2) Original Labs_SU, (3) Original Labs_Trinity, and (4) Original Tutorials_Sewanee. They contain the original, unedited materials submitted by each participating institution, as part of their institutional requirement for fulfilling the SODA grant. The unmodified materials are included for several reasons: (1) Some of the labs are observational, meaning they are to be done by actually looking through a telescope and timing events (such as the drift of a lunar feature across the field of view) or measuring features using a special reticule eyepiece. The original lab write up would then be of little use to an astronomy student without access to a telescope and instrumentation. On the other hand the original lab would be very useful to students at those institutions that do have such instrumentation. (2) In the lecture–lab paradigm of science classes the lengthy introductory sections of the SODA may not be viewed by some instructors as being necessary. The PI of this grant hopes that having both original and modified labs available for comparison will illustrate that a substantial amount of information, usually relegated to (usually ignored) lectures, will prove liberating for instructors because they do not need to push as hard to cover material and can instead focus the lectures, that they do give, on interesting astronomy topics that do not lend themselves to laboratory exercises. (3) Finally, the unmodified labs are provided to show that this grant was more then just collecting labs from different ACS institutions. To convert these labs to SODA labs required a lot of work!

**The ProImages Folder:**

The ProImages folder contains reduced (i.e. 'Pro'cessed) asteroid and comet images from the Cordell-Lorenz Observatory, courtesy Dr. Doug Durig, Sewanee: The University of the South. The images are taken with a Meade$^{TM}$ 12 inch LX200 Cassegrain ACR telescope, hyperstar equipped to reduce the focal length to f-2.8. (Translated, the above means the instrument is a long focal length telescope retrofitted to be a short focal length telescope with a wide field of view of the sky.) Within the folder there are two sub folders called AsteroidProjects and CometProjects. The AsteroidProjects folder contains image data sets for four asteroids. The CometProjects folder contains image data sets of five comets. Each image data set consists of dozens of images in FITS (Flexible Image Transport System) format. The format is a standard professional astronomy format. The headers of the files contain valuable information that assists in the analysis of the image. Virtually all, off the shelf, astronomy image processing and analysis software can read FITS files.

**2. SU SODA Grant Resources:** Receiving this grant enabled the PI to leverage an additional in house Brown grant (value about $5000) at Southwestern University for the procurement of small telescope equipment needed to fully implement a SODA class on the SU campus. A beta version of the class was tested during the 2009-2010 academic year in a three credit hour course at SU called “Exploring the Universe”. SODA labs in development (and not part of the submitted group of labs) were tested in this course. Education consultant Co Investigator Dr. Michael Kamen (SU) provided insight about conceptual tripping points in a moon phase lab and a retrograde motion lab that was a part of this course. Full implementation of the SODA course occurs this Fall (2010) when, as part of an across the SU campus curricular reform movement, Exploring the Universe becomes a four credit hour course. This change is vital to making the SODA concept viable because extra class time is needed to carry out SODA related activities.

During the period of this grant the PI faced a ‘perfect storm’ of time consuming delays (first time department chair, a staffing shortage due to sabbatical leave, a two semester introductory physics course with over sixty students and no grader, becoming the physics lab super and an extra physics lab instructor when an adjunct developed a heart condition, necessary but time consuming curricular reform work, preparing for a ten year departmental review, and a car wreck!) The delays made it impossible to use the allotted travel funds to make presentations at meetings or to travel to other ACS colleges. (Note: The PI did send out a request to the participating ACS colleges asking to be invited but did not get any offers.) Permission from ACS administrator Marcia White to re-allot the travel funds for summer student assistance was obtained and a due date extension granted. SU students Sarah Doty and Jennifer Heaton were hired. They tested SODA labs, created images that were inserted into SODA labs, and wrote initial or augmented drafts of introductions to SODA lab contributions. In addition they spent two weeks developing a small telescope flat field projection device. The device provides a uniform illumination field for the purpose of calibrating science images. It will be used by students doing astronomical imaging projects in the SODA class this fall (2010).

Additional funds from Furman College were re-channeled into SU to be used as equipment. It was the intent of Co-Investigator David Moffett at Furman College to produce a Radio Astronomy lab contribution to the SODA labs. Unfortunately there were equipment problems at his institution (However see his report below.) and in addition he was not able to recruit a student for the project. The funds were therefore returned to SU. The funds were used to procure a telescope mount, filters and related equipment (refer to the separate SU budget report) that will be used this fall (2010). In particular the mount is needed so that two small telescopes with imaging cameras (procured by the leveraged Brown grant) can be set up at the same time allowing different imaging projects to be carried out simultaneously.

It is recognized that dissemination of the SODA lab product is an important component of this grant. As part of the budgetary realignment the PI has agreed to use his own SU personal discretionary funds to travel to and present the SODA lab product at the upcoming American Astronomical Society meeting in Seattle Washington in January 2011.

**3. Individually submitted final reports from non SU Co-Investigators:** Brief reports were requested from non SU Co-Investigators, by the PI, for inclusion into this report. These are presented below. According to these reports, the Mellon Foundation supported SODA grant: (1) successfully spurred student professor collaborations, (2) enhanced faculty development and renewal by enabling faculty to attend science or science education meetings, (3) resulted in student presentations of SODA projects at science or science education meetings, (4) allowed for the procurement of instrumentation that will facilitate hands on astronomy education, (5) assisted in public education and outreach through the mentoring of high school students doing summer astronomy projects, and (6) leveraged the outlay of additional internal resources, by individual ACS colleges, toward science instrumentation and education. The individual reports are as follows:

**SODA Grant Final Report: Hendrix College**
**Co Investigator: Dr. Ann Wright(faculty), Ryan Strickland (undergraduate student)**

Dr. Ann Wright and student Ryan Strickland completed the work for the Student Observation Driven Astronomy (SODA) across the ACS grant for Hendrix College. They developed an introductory Astronomy lab on the topic of Spectroscopy. The lab contained three parts: interference of monochromatic light from a double-slit, emission spectroscopy using a diffraction grating, and the analysis of star and galaxy hydrogen emission lines using the Sloan Digital Sky Survey. The lab was included in the PHYS 160 Astronomy class taught during Maymester in 2010.

The following supplies were purchased using grant funds:

1. Orion Variable Polarizing Filter
2. Orion Glass Solar Filter
3. several components to mount a digital camera to our telescope

These supplies were used in PHYS 160 Astronomy, taught during Spring 2010 and Maymester 2010, to view sunspots. The grant also supplied reimbursement for a trip to pick up a 12 inch Cassegrain telescope that was donated to Hendrix College.

Dr. Ann Wright travelled to NASA Kennedy Space Center in Florida from April 1-5, 2010. The trip was funded by Arkansas Space Grant Consortium and the SODA grant. The trip included a VIP tour of NASA KSC, a workshop conducted by the NASA Education Department entitled "Women in Robotics and Engineering" and a VIP viewing of the launch of STS-131 from the Banana Creek viewing location. Pictures from the trip can be viewed at

<http://www2.hendrix.edu/astronomy/ksc/ksctrip.html>.

The purpose of the workshop was to gather people from K12 education, colleges, and professionals to discuss ways to recruit and retain females in the areas of space science.

**SODA Grant Final Report: Sewanee, The University of the South**
**Co Investigator: Dr. Douglas Durig**

May 11, 2010

To whom it may concern:

I used the materials prepared for the ACS Mellon Faculty Renewal grant in the Bridge program for high school science and math students in the summer of 2009 and it resulted in several publications for these high school students. I also worked with a summer intern that summer to collect data and had a student do a presentation for Scientific Sewanee. I provided several members of the group with copies of the laboratory exercises and data sets, to be passed on to other educators in the group and in Chattanooga. I feel that these activities met the requirements for dispersal of the products of this grant.

Respectfully submitted,

Dr. Douglas Durig

**SODA Grant Final Report: Trinity**
**Co Investigator: Dr. David Hough (faculty), Gareth Jones (undergraduate student)**

We prepared three astronomy labs that make use of archival and recent data obtained at the Trinity University Observatory using our Meade LX-200 8" and 16" Schmidt-Cassegrain telescopes: a lunar feature measurements lab, an exoplanet transit lab, and a stellar spectra lab.

Lunar Feature Measurements: Measurements of crater diameters or mountain heights are very traditional and have been done for years. Our main goal was to write a comprehensive lab that would consider not only the simple, ideal cases - crater diameter measurement near the Moon's center, or shadow measurement for height determination at first-quarter - but to deal with general cases for wide ranges of feature location and lunar phase. We provide detailed discussion of the effects that are included in the various calculations, and also of other effects we neglected; the latter we hope will be useful in helping students to understand how scientists make valid approximations. Sample data obtained visually with reticle eyepieces are included for crater diameter and depth measurement.

Exoplanet Transits: Extrasolar planets were discovered only 15 years ago, and this has now become one of the dominant fields of modern astrophysical research. We discuss the various techniques that have been used to discover exoplanets and determine their properties. Our main goal was to outline the methods for observing and analyzing data for those fortunate cases where a planet transits, or passes in front of, its star. We discuss how, with some complementary data from the literature, students can use transit observations to determine the size of a planet's orbit, as well as its radius, mass, density, and temperature. Sample data from CCD photometry are included for partial transits of the TrES-4 system.

Stellar Spectra: The observation and analysis of stellar spectra are of central importance in astrophysics for learning about the physical properties of stars and their composition. We review the basic physics of blackbody continuum emission and spectral absorption lines. Our main goal was to describe methods students can use to obtain spectra of bright stars and analyze them to classify stars based on continuum properties (spectral peak and shape) and spectral line properties (which lines are present, and their relative strength). Sample data from CCD spectroscopy are included for six bright naked-eye stars spanning nearly all the spectral classes.

Gareth Jones made a presentation on this work at a meeting that he and Dr. Hough attended in October 2009. It was the Fall 2009 meeting of the Texas Sections of the American Physical Society and American Association of Physics Teachers, along with Zone 13 of the Society of Physics Students. The presentation was entitled, "Student Observation Driven Astronomy at Trinity." The abstract is published at this link:

http://meetings.aps.org/Meeting/TSF09/Event/113917

A separate financial report is being submitted. We summarize here that Trinity's $1,230 SODA funds were nearly fully expended to contribute to undergraduate Gareth Jones' wages, to support our travel to the Texas state physics meeting, and to purchase superior imaging software that will serve our lab students better. Trinity University made a special investment in this project with a $1,142 Curricular and Pedagogical Innovations Grant that helped to provide full-time salary for Gareth Jones during his period of summer work on this project in 2009.

Dr. David Hough (faculty)
Gareth Jones (undergraduate student)
Submitted June 23, 2010

**SODA Grant Final Report: Furman**
**Co Investigator: David Moffett**

For our contribution to the SODA project, Furman University utilized its radio astronomy resources to conduct a galactic plane survey of neutral hydrogen (HI). Hydrogen emits a spectral line at 1420 MHz, or 21-cm wavelength, due to an electron spin-flip transition (see figure below). Students can process observations of this spectral line to study the effects of the Doppler shift as the observed velocity of hydrogen clouds in the Milky Way changes along the galactic plane. Students can also perform an advanced project using these observations by decoupling the contribution of Earth's motion from the Sun's orbit around the Milky Way to determine a local system of rest (LSR) velocity and utilize it to determine the velocity of hydrogen clouds at different radii from the center of the galaxy.

We began the survey observations at Furman by using our 2.3-m radio telescope; however, hardware issues kept us from completing the survey using this instrument during the period of the project. Fortunately, we had access to another telescope at the Pisgah Astronomical Research Institute (PARI) and completed the project using their 4.6-m radio telescope. The telescope's receiver operates at a center frequency of 1420 MHz, and its spectrometer was configured to record 240 channels, 5 kHz wide, for a total bandwidth of 1.2 MHz. We recorded HI emission from a range of galactic longitudes: from 1 to 247 degrees, and from 349 to 359 degrees, in steps of 2 degrees (nearly the resolution of the telescope).

We are in the process of completing the laboratory exercises that utilize these data. Preliminary results of this project have been presented to staff and students at PARI, and will be presented at regional astronomy conferences this autumn in South Carolina and Georgia. PARI is a not-for-profit foundation dedicated to providing hands-on educational and research opportunities for a broad cross-section of users in science, technology, engineering and math (STEM) disciplines.