of the moons relative to the planet, students will be able to use real data to deduce Kepler's laws.

These exercises are being developed by our astronomy students under the direction of faculty. Thus, not only will introductory students use observations obtained with our CCD system, but also the astronomy majors will learn how to obtain accurate CCD images and how to develop useful laboratory exercises. Motivated students will be encouraged to undertake an observing project of their selection — in which they participate in all the steps involved in selecting a suitable object to observe, followed by obtaining, calibrating, and analyzing the CCD image. It is our hope that students will be excited by using results obtained from a research-quality instrument that is located on our campus.

3. Acknowledgment

Funding for the purchase of the CCD system was provided by a National Science Foundation-College Science Instrumentation Program grant and by Colgate University. Support for student participation in developing laboratory exercises has been provided by a Sloan Foundation grant to Colgate University. Once development of these projects is completed, we expect to make our images and exercises available to interested educators. We welcome any comments or inquiries about our CCD system or laboratory exercises.

MODERN PHOTOMETRY LAB EXERCISES FOR STUDENTS IN INTRODUCTORY ASTRONOMY

Daniel B. Caton
Department of Physics and Astronomy, Appalachian State University,
Boone, North Carolina 28608 U.S.A.

Introductory astronomy lab exercises have traditionally been rather simple in nature — observations are often limited to visual observing, sketching, and perhaps photography. These types of labs are more like 19th-century astronomy than the techniques used by modern astronomers. Students should also be introduced to *quantitative* work in astronomy, in the same way that they are in equivalent introductory physics and chemistry labs. A typical solution to some of these problems has been to use published data (for example, the *Sky & Telescope* lab exercise series) to provide numerical work. This is less satisfactory for the student than obtaining his or her own quantitative data to reduce and analyze.

At Appalachian State University we have been working on the development of a set of modern lab exercises that address the needs discussed above. The first of

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these are photometry exercises that use a readily available photometer, the Optec SSP-3 (Optec, Inc., 199 Smith St., Lowell, Michigan 49331, U.S.A.). This photometer is ideal for student use in that it is compact, durable, user-friendly, and relatively inexpensive. Its PIN-diode detector does not require the high voltage that a photomultiplier needs. The photometer operates off a rechargeable 9-volt battery that will run it for a typical lab session. The controls include a two-position filter slide, flip-mirror knob, and switches for scale and integration time. The output is displayed as a four-digit number on red seven-segment LEDs (for advanced student projects, the output is also available as a 0-10 kHz TTL-level pulse train that may be integrated by a microcomputer).

The photometers are used on Celestron C-8 (20-cm) Schmidt-Cassegrain telescopes. Our observing lab/deck is equipped with twelve of these telescopes and photometers, each telescope used by a pair of students. Two dozen students seems to be the maximum that may be easily managed by an instructor and student-helper.

Before using the telescopes with the photometers, the students are introduced to the instrumentation indoors and then learn to use the telescopes, visually, outdoors. Then the students are introduced to the photometers, again indoors. They learn the basic techniques of photometry by observing artificial stars. The "starbox" is simply a cardboard box with a couple of light bulbs mounted in it, and a metal plate with various size holes drilled in it. Colored plastic over the holes provides a variety of star colors (about 0.5 magnitude range in B-V). The students learn to take data, remove the (artificial) sky from the readings, and calculate magnitudes and colors. These computations are done by hand, using calculators, to provide them with some knowledge of what magnitudes and colors mean.

After the indoor introduction the students use the photometers and telescopes outdoors to observe a variety of bright Johnson standard stars. They learn that the effects of our atmosphere must be taken into account. This requires that the time of each observation be recorded. For this purpose we provide some digital clocks that display the time on 2-inch tall LEDs. The clocks are set to the sidereal time before the lab begins — the sidereal/solar rate drift during the lab session is unimportant for their work.

Doing quantitative work outdoors requires some precautions by the instructors as well as some care by the students. The instructor must be sure that the telescopes do not dew up during the evening, and that the observing conditions remain good enough to get meaningful results. The students must learn to center their star in the photometer's reticle carefully, and to handle the photometer gently so as not to cause the instrument to drift. Centering should be checked after each filter change, and at the end of the last measurement on an object. The students must learn to note whether their numbers seem reasonable, or whether a sudden change indicates drift, clouds passing, or that someone walked in front of their instrument. One should note, though, that some of these are the same concerns of professional astronomers, and that the students will learn to appreciate the difficulty involved in obtaining good scientific data!

Having obtained their data, the students use the next cloudy lab night to reduce their measurements to outside-atmosphere magnitudes and colors. The extinction coefficients for the night are predetermined by the instructor, using data from early and late lab sessions held each night. Instead of doing the calculations by hand the students use microcomputers, running a photometry reduction program written for them in BASIC. They enter their measurements, times, photometer settings, and star identifications, and the program computes and displays the outside-atmosphere magnitudes and colors. The student then plots these results *versus* the Johnson values, providing a calibration for his/her instrument. This calibration may be used to identify the Johnson magnitude and color of an observed "unknown" star, and may be used later in the Pleiades project.

After learning to use and calibrate their instrument, the students are ready for an interesting exercise in observational astrophysics: obtaining their own color-magnitude diagram for the Pleiades, and using it to estimate the cluster's distance. They are provided with a finder chart of the Pleiades and a star identification list containing the spectral types of the numbered stars. It is explained to them that they are responsible for picking a range of spectral types to get a good color-magnitude diagram. They are to make two measurements in each filter (B and V) of as many stars as possible in the two-hour lab session. In practice, the best students can measure 15-20 stars; the least capable students get about half of this number. The practical limit to the photometer on the C-8 is about visual magnitude 10. In some ways it is an easier project to star-hop in the Pleiades than it is to set the telescope on the several standard stars used in the first outdoor project. The field of view in the Optec viewer, on the C-8 telescope, is about 20 arc-minutes.

Again, the next cloudy lab night is used to reduce and analyze the data using a modified version of the microcomputer program. The reduced data are transformed to the Johnson standard system using either the previous calibration lab results or the Johnson values provided for one of the Pleiades stars. The color-magnitude diagram is plotted on one set of axes, alongside a standard H-R diagram. The vertical shift between the C-M and H-R diagrams is measured and used as a distance modulus to compute the distance to the cluster. Students who worked carefully to obtain good data are able to get results that are in good agreement with published values of the distance. Figure 1 shows one student's results. The few stars that fall far from the main sequence are in most cases known to be field stars or double stars. The increased scatter at the lower right is due to noise in the photometer near its sensitivity limit. The students are not forewarned about these problems since the discussion of these problems is a good lesson in itself!

A package of sample lab exercises, computer listings, instructor suggestions, and other helpful materials for performing photometry labs is available upon request from the author. This project was supported by grant # CSI-8551003 of the National Science Foundation's College Science Instrumentation Program.

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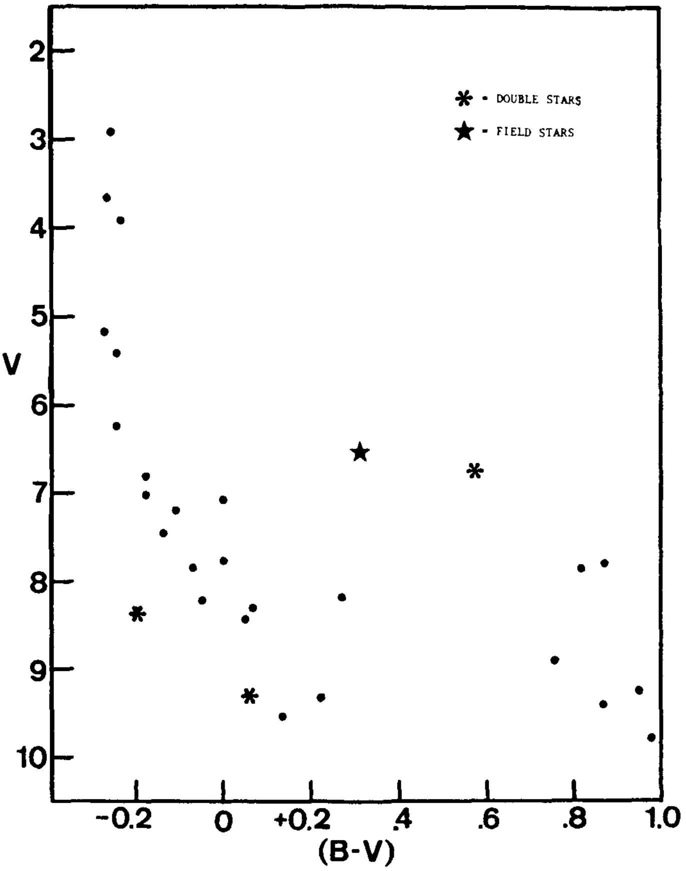

Fig. 1: The color-magnitude diagram of the Pleiades.

Discussion

M. Dworetsky: *A possible improvement of the indoor exercise might be to use a photofloodlamp rather than an ordinary light bulb. This could provide more blue light. Disposing of the heat generated could be a problem, of course.*

L.C. Hill: *Do you find that you have to hold the students' hands while working through the calculations of logarithms and magnitudes? Do some students get lost in the calculations?*

D.B. Caton: This is always the question of how much cookbook work should be used and how much the students should thrash out the questions for themselves. Some just don't make it — and that's life.

H. Shipman: *This exercise requires relatively good weather. I realize the weather on your campus is pretty good, but on how many nights is it good enough to work outside* *but not good enough to get a decent main sequence? Also, you mentioned that once they get data, they're set for 3–4 nights inside reducing their data. There is still a problem: you have to decide five minutes before lab starts whether the weather is OK.*

D.B. Caton: Out of 15 lab nights per semester, we will have perhaps five that are photometric and two or three more that are good enough for visual or photographic work. The problem with last-minute weather changes *is* indeed still a problem since it takes about 30 minutes to set up the telescopes. We always have both an indoor and outdoor lab exercise ready each lab night.

H.S. Gurm: *How about using a 6" or 8" Cassegrain with a larger f-ratio instead of a Celestron, particularly when doing photometry?*

D.B. Caton: I see no problem with using a six- or eight-inch Cassegrain to do photometry. Our Celestrons were chosen for their reliability, availability at competitive prices, and wide range of accessories available from both Celestron and second-source manufacturers.

L.A. Marschall: *1) How many labs does this exercise take; 2) and how many students do the lab each semester?*

D.B. Caton: 1) One lab indoors and one lab outdoors. Good students get about 20 Pleiades stars in two hours. Average students get about half that number. 2) About 75 students per semester, in three groups of 24. The students work in pairs.

CRATERING IN THE CLASSROOM

Walter Bisard
Central Michigan University, Mt. Pleasant, Michigan 48859, U.S.A.

The SEMS Project (Science Education in Middle School) in Michigan is a cooperative science education improvement effort by several universities, hundreds of school districts, and the state department of education. Upper elementary and middle/junior high school teachers have been targeted for improvement of science instruction. Although the initial area of focus included teachers of grades five through nine, the project has been successfully extended to early elementary grades. While there are many excellent teachers at these grade levels, research findings indicate that 49 per cent of all middle school science teachers are teaching without a major or minor in science! The situation is even more critical at the upper elementary levels.

In an effort to improve science teaching at the upper elementary and middle/junior high school levels, over 300 well-qualified teachers were selected to be