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Abstract

The availability of small, inexpensive CCD cameras is making it possible to offer non-science students in introductory astronomy courses hands-on experience in astronomical imaging. For the past three years at Gettysburg College we have been developing laboratory exercises using ST-4, ST-6, and Lynxx CCD cameras attached to 8-inch telescopes. We discuss the hardware and the procedures involved in these exercises, pointing out the benefits and limitations of digital observations with introductory students. We also offer tips for making successful observations with students, and describe plans for further development.

1. Introduction

Thirty years ago, a friend of mine, now an English professor in New England, took an introductory astronomy course from Peter van de Kamp at Swarthmore College. He remembers few of the details of astrophysics that he learned there, and with the rapid changes in astronomy during the intervening years, much of what he did learn has no doubt been superseded. What he does remember, however, is going out night after night to observe the brightness of Delta Cephei, constructing for himself a light curve of the variable. Seeing the workings of the heavens firsthand made a more lasting impression on him than the dry facts and figures of the lecture hall.

Observations, of course, lie at the heart of astronomy. Yet I would venture a guess that only a small fraction of the many non-science students who take astronomy each year come away with memorable experiences of systematic observations with either naked eye or telescope. Many astronomy courses offer no laboratory experiences at all. When labs are offered, the exercises often involve analyzing images others have taken, or plotting up tables of data, reading graphs, and making diagrams.

It is not hard to understand why this is. Most of the objects of interest in astronomy are too faint to be seen easily with the naked eye or small telescopes. Even the brighter objects are becoming hard to see in light-polluted environments. Phenomena in the sky take place at a pace that does not fit well into weekly two- or three-hour lab sessions, and observations in many climates are often frustrated by weather. In addition, astrophotography, until recently the technique most commonly used to record data, requires patience, complex equipment, and messy, time consuming processing.

It is a shame that so few of our students get hands-on experience in astronomy. For many non-science students, astronomy is the only science course they will take in their college careers. If we want to help produce a public with an appreciation for what science is and how it is done, we should be concerned about providing more hands-on experience for these students.

The new technology of electronic imaging using Charge Coupled Devices (CCD's) and computer image processing affords an attractive and effective way to get students out at the telescope doing real astronomical observation. At Gettysburg College and a number of other colleges (e.g., The University of Iowa and Appalachian State University), introductory astronomy labs are beginning to incorporate exercises based on this technology. We discuss here some of the history of our efforts at Gettysburg, the advantages and limitations of the technology, and some of what we have learned about how best to use CCD's in introductory courses.

2. CCD Cameras at Gettysburg

Professional astronomers have been using CCD's for over a decade, and within the last few years CCD's have supplanted photography for all but a few specialized applications. Until recently, however, they were too complex and costly to find much application in astronomy education. In the late 1980's and early 1990's, a number of relatively inexpensive off-the shelf cameras became available, notably the Photometrics Star-1, the Santa Barbara Instruments ST-4 and ST-6, and the SpectraPhysics Lynxx. These cameras could be easily connected to personal computers (PC's), and offered unprecedented power for imaging faint objects with even the modest-size telescopes available at many colleges.

Gettysburg College purchased its first CCD camera, an ST-4, to attach to a 4-inch guider/finder telescope mounted on the College's 16-inch reflector. We were so impressed with the capabilities of the device that we submitted a proposal to the National Science Foundation to equip six existing Celestron 8 telescopes with CCD cameras for use in a two-semester introductory astronomy course that enrolls about 100 students each year. Between July 1991 and July 1993, with NSF support, we purchased three Lynxx cameras and two ST-6 cameras, which are now in regular use in our introductory astronomy labs.

The equipment is used on an outdoor observing pad adjacent to the Gettysburg College Observatory, which is at the northwest edge of our campus. The telescopes, which are stored in the Observatory building, can be quickly mounted on concrete piers using index pins in their wedges for quick alignment. Mobile observing carts, containing PC's to run the CCD cameras, can be wheeled out of the nearby building in a matter of minutes and connected to the cameras. The carts are also used for storing cables, cameras, and associated hardware (see Figure 1). Images are stored on the PC's hard drive and can later be transferred to a floppy disk and displayed on PC's in a lab room in the Physics building (we have 10 PC clones there with Super VGA (SVGA) graphics screens) or on the students' own computers.

Twice each semester each student in the class gets a chance to use the equipment. Were our classes smaller, the staff larger, and the weather better, we would give each student more observing time, but even the limited exposure our students get seems to have been beneficial. All of them seem to rate astronomical imaging as one of the highlights of the course. Before CCD's, when students could only see a few faint smudges of light through the eyepieces of our telescopes, they had far less interest in observing and far less appreciation of how astronomy is actually done.

3. Advantages and Limitations of CCD Cameras in the Introductory Laboratory

3.1. Advantages

The advantages of CCD cameras are evident to anyone who has used one. We list four major features below, each of which makes them ideal for use in the introductory classroom:

a. CCD cameras are very sensitive

Because they produce images so rapidly, students do not have to learn how to guide carefully to get usable images. For bright objects like the moon and planets, no guiding is necessary, and if telescopes are carefully aligned, even faint objects like planetary nebulae and galaxies can be imaged with a minimum of effort. Some camera software, like that provided with the ST-6, has built-in digital image-stabilization options that make manual guiding unnecessary.

The sensitivity of CCD chips also makes it possible to produce very short-exposure images of planets which are relatively unaffected by seeing, sharper by far than those obtainable with photographic methods. Many (but not all) of the inexpensive cameras on the market have mechanical shutters with speeds as fast as 0.01 second.

Finally, the rapid response of CCD cameras makes it possible to take many images during a single evening lab period. This not only reduces student impatience, but it enables instructors to make productive use of precious observing time, especially in climates like those at Gettysburg, where on the average only a third of the nights are clear.

b. CCD cameras have large dynamic range

While photographic emulsions can respond at most to a range of about 100 in brightness, CCD's have a dynamic range of between 50,000 and a million. This not only makes it possible to capture a wide range of magnitudes on a single image (for instance the stars in an open cluster), but also makes it difficult to produce an unusable exposure. If a student produces an exposure containing only a few counts, it is a simple matter to remap the pixel values in the display with an image-processing program so that the image appears brighter. Of course, shorter exposures have smaller signal-to-noise, but students obtain much satisfaction out of seeing something where photographic techniques would reveal nothing. And the rapid response of the CCD camera makes it easy to retake an image if the exposure isn't right.

c. CCD cameras are linear

Photographic emulsions are notoriously non-linear, suffering from reciprocity failure at low exposures and saturation at high exposures. CCD's are effectively linear up to the point where the charge carrying capacity of each pixel is exceeded (see item 2 above). The lack of reciprocity failure makes it easier to get images of faint objects, and the overall linearity simplifies photometry.

d. CCD cameras are digital

Images can be easily stored and manipulated using PC's. Students can take dozens of images in a single night, and can discard all but the best for study at a later time. There are no messy chemicals, and practically no delay between the time the image is taken and when it can be examined.

Furthermore, introductory astronomy students who use CCD's are experiencing astronomy more the way practicing astronomers do. Modern telescopes are all run by computers and CCD's, both for direct imaging and spectroscopy.

Students respond well to this. Computers and networks are becoming ubiquitous, and most students are familiar with the fundamentals of how to use them. (Gettysburg, a school of 2000 students, has almost 1000 computers on its network, and many students have their own.) Thus doing astronomy draws on techniques they have encountered elsewhere, both in school and in the world outside.

3.2. Limitations

Electronic imaging, however, is not without its disadvantages in introductory labs.

The overriding problem is that CCD chips are still small compared with photographic film. The TC-211 chip used in the Lynxx and ST-4 cameras, for instance, is only 2.6 mm square. Depending on the telescope, the limited field of view of the chip (5 to 15 arcminutes is typical) may restrict its use to only certain imaging applications. In any case, pointing the telescope accurately enough to get an object on the chip can be quite difficult.

Other problems are not unique to CCD's. Despite their ease of use, CCD cameras cannot compress time; astronomical phenomena that occur over long periods of time cannot easily be observed by a single student in the limited time available.

In the section below, we discuss some of the laboratory exercises we have tried out at Gettysburg, and we note our experience in dealing with the advantages and limitations of CCD imaging.

4. Making Successful Observations in Introductory Labs

When we first proposed using CCD cameras for our labs, we identified five "core" exercises we wished to implement. Three of these have been successfully introduced during the 1992/93 academic year, the first year since the cameras were installed.

We offer one introductory lab on digital imaging using computers in our astronomy lab room. Students examine images taken with campus telescopes and by spacecraft like the Voyager. They learn about how digital images are displayed, processed, and measured. This provides preparation for work at the telescope. We currently use the program IMDISP, developed at the Jet Propulsion Lab, for display and analysis.

In a second lab, students take images of craters on the moon, later measuring the heights of lunar mountains by measuring the lengths of shadows. We have identified a number of features, like the mountains Piton and Pico, which are best suited for this at various phases of the moon between waxing crescent and just past first quarter (the phases when most early-evening labs can be held). Using a C-8 telescope, shadows 10 pixels long can be obtained with a Lynxx camera, easily measurable by students (see Figure 2).

In a third lab, students take images of deep-sky objects such as planetary nebulae, globular clusters, and galaxies.

Two other labs are still being developed. In one, students will take a series of images of a variable, measuring differential magnitudes with comparison stars on the frames to construct a light curve and determine its period. In the other, students will determine a color magnitude diagram of the central region of M67 from B and V images. The giant branch of this cluster extends down to V = 12.5 (Montgomery, Marschall, and Janes 1993), a magnitude easily obtainable with our cameras.

We plan to try other exercises as time and resources permit, including imaging of comets, measurement of the motion of asteroids, determining the mass of Jupiter from observations of its satellites, and color imaging.

As we have tried these exercises out with our students we've learned that the use of CCD's still requires quite a bit of skill and preparation. Introductory students, who have neither the time nor the patience of dedicated amateurs, will not be able to find anything but the brighter planets unless telescopes are well-aligned and easy to point.

A flip-mirror previewer is a prime necessity: it assists in both finding and focusing. These two functions are related. It can be very time-consuming to focus a small-format CCD camera by trial and error, especially if one is not sure the image is on the chip. A good flip mirror, set up so that an object is in focus on the chip when it is in focus through the eyepiece, makes things easier. Motorized focusing controls are also useful. They permit accurate focusing without jitter, making it possible to touch up the focus when looking at a dim or small object. Finally, digital setting circles and motorized slow motion controls are necessary for easy finding of deep-sky objects.

This raises the cost of equipping a lab for CCD observation beyond the simple cost of the camera. Indeed, the cost of a camera may account for less than half of the cost of an observing setup. Including PC's, digital setting circles, flip mirrors, and filter holders, we estimate that a single observing station will cost $4000 to $5000, not counting the telescope.

Even with the increased ease of use that CCD's provide, students still do not have the time to make all the observations necessary to carry out many simple projects. Stretches of bad weather have frustrated our attempts to get images of the moon at just the right phase for good shadows, for instance.

Yet we have found that students like to take images, and learn a lot doing so. Therefore we have settled on a strategy where students take many images for several projects during an evening lab. If some images are suitable for later analysis, that is good. If they are not, or if the night is not ideal for a particular mountain shadow or variable star phase, we draw from a pool of images produced by other students or at other times. Thus students get experience in both taking images and in reducing the data from the images - though not necessarily from the same images they took.

Some of our students enjoy the CCD astrophotography so much that we are planning to print up the best images and display them on a bulletin board, with a prize awarded for the best image of the semester.

5. Final Thoughts

We have been using CCD's in the introductory astronomy laboratories for only one year, but we are encouraged by what we have learned. Not only have we been able to increase the hands-on component of our introductory course, but we also find our students increasingly literate in digital imaging techniques, making it easier to incorporate digital measurements of images into what might otherwise be dry analysis of photographs and charts. For instance, we are introducing a lab on the measurement of the parallax of asteroids into our second semester course. The lab uses images taken with two CCD cameras at opposite sides of the country (Marschall, Ratcliff, and Balonek 1993).

In the future, larger chips, more powerful computers, and simply more experience will add to our capabilities for bringing the universe into the classroom. We look forward to the future, and to more and better hands-on exercises for our students.

6. Acknowledgements

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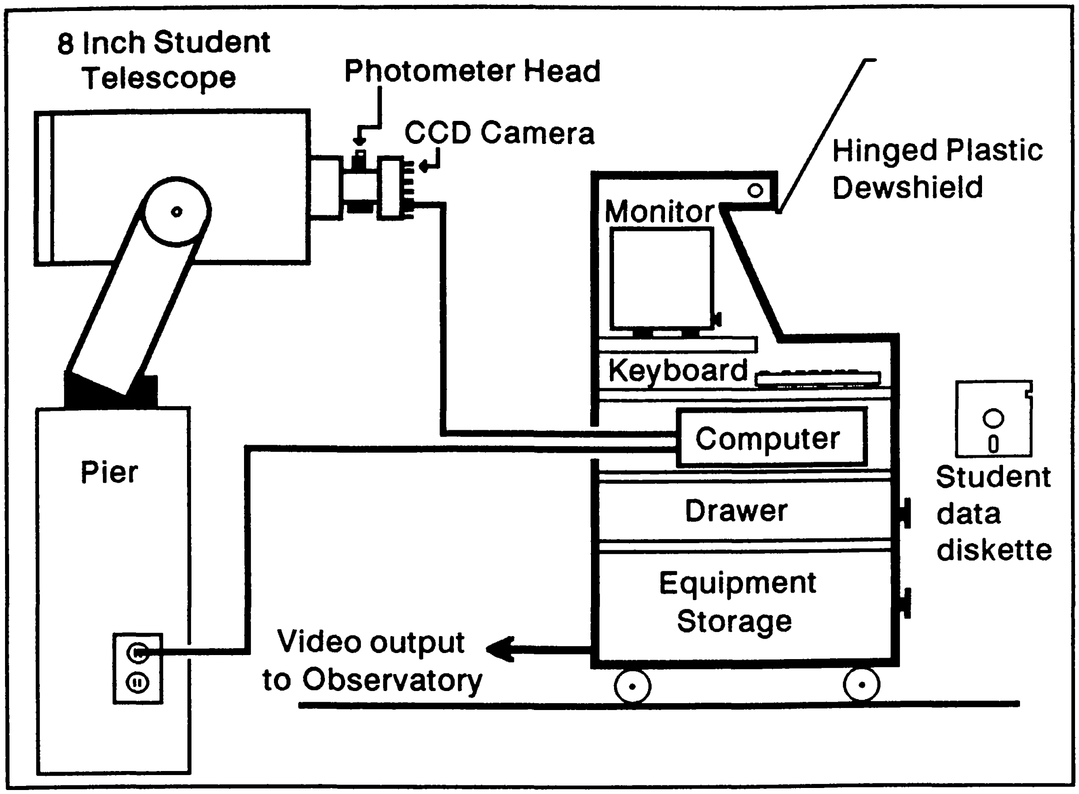

Figure 1. Diagram of the mobile observing carts used at Gettysburg College Observatory.

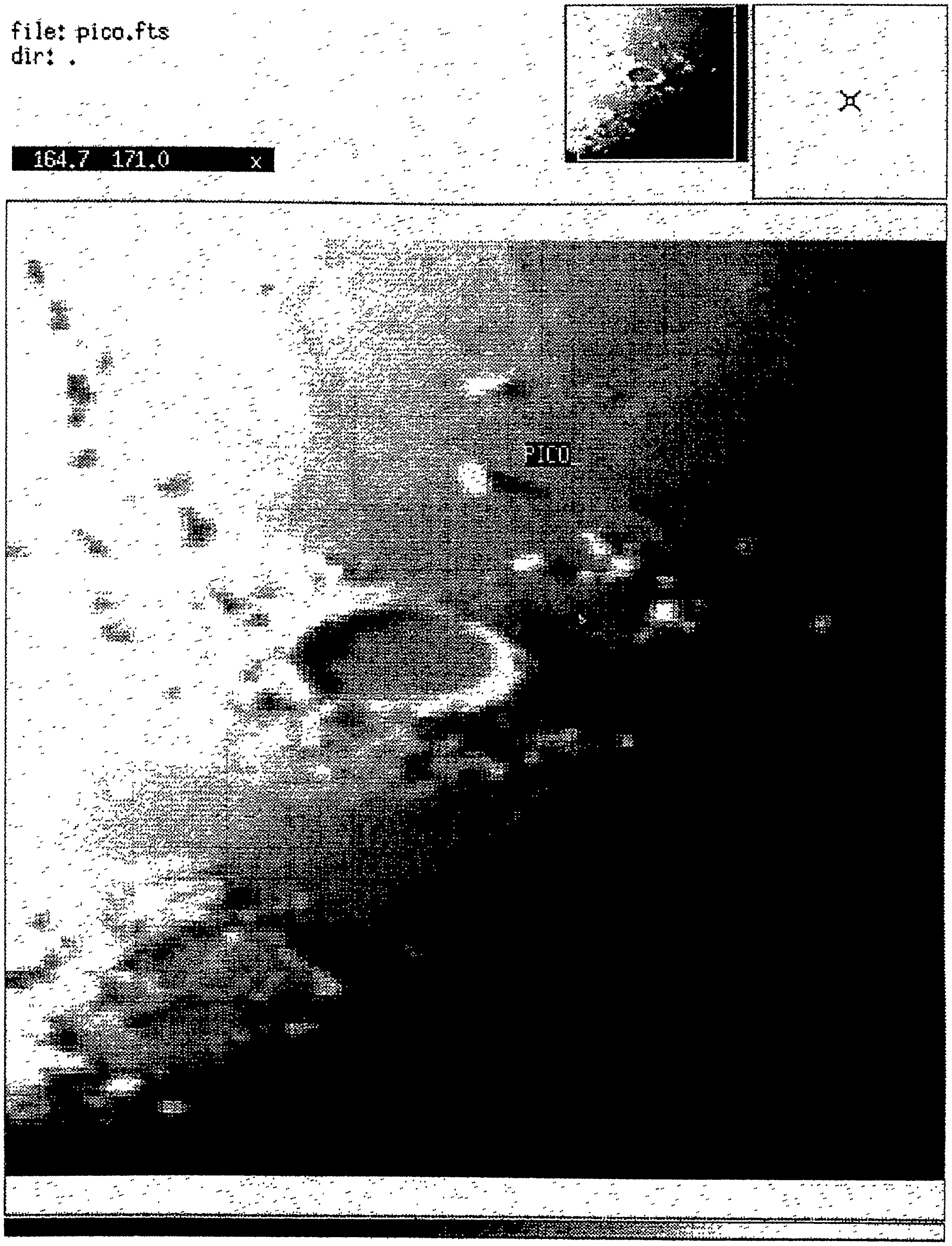

Figure 2. Image of the moon used for the determination of the heights of lunar mountains. The shadow of Pico is shown. The image was taken by Michael B. Hayden on November 3, 1993, at 23:30 UTC, using a Lynxx CCD camera attached to a Celestron C-8 telescope.