UNIT 60

THE CCD CAMERA AND IMAGE PROCESSING

GOALS: After mastery of this Unit you should understand basic image processing functions and have learned some of the applications of CCDs.

The invention of the CCD camera and development of image processing have enabled universities with smaller instruments and poor locations, as well as amateurs, to carry out research projects that were once in the realm of professional astronomers with the large telescopes. This unit will provide the opportunity to take and process images with the ST-5 camera at Melton Observatory. Then using that image measurements can be made.

ASSUMED BACKGROUND: It is recommended that you be familiar with the Small-Angle Equation (Unit 3) and have completed Unit 59.

MASTERY will consist of successfully completing a 2.5 hour session to be held at Melton Observatory. This unit will be available when scheduled. When sign-up sheets are posted, you may pick up additional material from Kinko's or download them from the Astronomy Homepage (http://astro.physics.sc.edu). *You are <u>required to read</u> this material before arriving at the observatory.*

OBJECTIVES: After completion of this unit, you should have:

1. operated the ST-5 and taken several images
2. processed some images
3. made measurements of either stellar separations or crater diameters from one of the processed images.

PART 1: TAKING AND PRODUCING A GOOD IMAGE

Several sources discuss the general methods for taking and producing a good image. Following is a description of the steps involved in taking an image with the ST-5 CCD camera at Melton Memorial Observatory. For planets and deep-sky objects, start before dark, then:

1. Decide on the target. Something rising or near the meridian will be in the sky longer giving you time to take more images. An object that is setting will not be visible for too long causing you to rush to take the needed images.

2. Decide on the telescope. The 16" will work very well with the planets. For larger objects, use the 4" to fit the object on the chip.

3. Turn on the CCD camera and adjust the temperature to 20 or 25 degrees below the ambient air temperature. During the summer it helps to have a fan blowing past the cooling fins of the camera. In the summer, if it takes more than 95% of the power to cool the camera, then the temperature is set too low and must be increased.

4. While the temperature of the camera is adjusting, start and set up the telescope. Make a directory for the images and change the telescope parameters as needed.

5. Hopefully, it is not yet fully dark. Point the telescope towards the evenly lit dusk (or dawn) sky and take several (>5) images. These are the flat-field images. Take several series each at different exposures that will be used throughout the night when taking deep-sky objects.

6. By now it should be dark. Find and center the target object in the telescope. Observe for several minutes to make sure the alignment and tracking are correct. [Optional- sketch and/or photograph the object before or after taking the images for later comparison.]

7. Do a preliminary focus by focusing the telescope with the smallest eyepiece available or by using the parfocal ST-5 eyepiece.

8. Take the eyepiece out and put in the ST-5 (with or without a projection assembly, color, or polarizing filters).

9. Use either CCDOPS or SkyPro to focus and position the object. This is the hard part. You might have to take several shots at different exposures to find the minimum where the object will be visible. Keep the auto contrast on. Then using that exposure, take several shots while focusing the telescope. When the object is almost focused, use planet mode to fine tune the focus. Once the focus is achieved, go back to full frame and center the object on the chip by carefully moving the telescope. For many objects, you can also use focus mode to find an exposure that does not saturate the chip and is still short enough not to show any drift in the telescope during the exposure.

10. You are now ready to take images (light frames). Use exposures close to but not past the saturation point of the object. Bright planets and the moon can saturate the chip in less than a second while deep-sky objects may take several minutes to overexpose. Single images and images in series should be taken.

11. For each set of images at a certain exposure, take a corresponding set of dark images at the same exposure. With the ST-5, this is done by covering the telescope so no light hits the chip. It is important to do this at roughly the same time as the other images so that the temperature of the camera is the same for both light and dark frames. Also a set of bias frames can be made while the telescope is covered but the exposure time is zero- well almost zero at 0.01 seconds. The dark and bias frame may also be made earlier before it is completely dark by covering the CCD camera during the exposures. However, the camera's temperature must be the same when taking any images.

12. Once you are done taking images, you can start processing them. First, average (use CCDOPS) each series of flat-field, dark, and bias images. For example, if you have seven series- three flat at X, Y, Z exposures, three dark at X, Y, Z exposures, and one bias. Averaging each series will result in seven images. From hereon, flat, bias and dark shall refer to the averaged image series.

13. Make corrected images of the flats by taking a flat and subtracting the bias frame. Then subtract the dark frame of the same exposure time as the flat frame.
    Flatcor(X) = flat(X) - bias - dark(X)

14. If the camera did not shift between exposures of an object, you can also average those light images.

15. Open either a single or averaged light frame. Subtract the bias and the appropriate dark frame.
    Lightcor(X) = light(X) - bias - dark(X)

16. Now ‘flat-field’ lightcor(X) by flatcor(X). The resulting image, if focusing was done properly earlier, should be sharp and clear- a good image. The background and range might have to be adjusted, but that is a minor operation. Further processing is optional. Most of the image processing functions in both programs are for aesthetic purposes and are therefore not recommended for images that are to be used for photometric or astrometric measurements. However, images that are not going to be used for measurements might benefit from more processing. ‘Playing’ with the image and functions is rather haphazard. Knowing what each function does and applying only those that are necessary should produce a pleasing image.

    $$\frac{\textbf{lightcor(X)}}{\textbf{flatcor(X)}} = \textbf{final image}$$

When taking images of the sun, follow the above steps with the following modifications to the listed step:

4. ...Remember to put a solar filter on the telescope as well as using the polarizing filter that is set to pass the least amount of light (looks dark when you glance through it). This is done to darken the image so that a longer exposure can be taken.

5. SKIP

6. ...The target object is a sunspot or group of spots. Center the spots and continue.

11. ..After taking the light, dark, and bias images, point the telescope to a clear region (no sunspots) of the sun and make the flat-field images.

The remainder of the steps are the same.

Exercise A:

1. The instructor will have already determined what object(s) will be imaged. You will have the chance to sketch the object, to calculate the magnification of the telescope view, and to determine the field of view of the telescope. the field of view of the camera will be given.
2. Some of the calibration images may have been taken earlier so that there is more time to take the light images and process them. Take the light images. Record the images taken in Table 1.
3. Process the images and record the image corrections in Table 2.
4. Answer the questions.

PART 2: APPLICATIONS OF CCDs

CCDs were first designed as an electronic analogue to the magnetic bubble device, a type of memory cell. However, the potential of the CCD as an imaging sensor was far greater than as a memory device. With the early and enthusiastic backing of JPL, CCDs have been quickly assimilated into the field of astronomy. Although CCDs are common in astronomy, they are also used in other disciplines such as physics and chemistry. CCDs are also becoming a part of everyday objects like camcorders.

Because CCDs are a nearly perfect sensor, better images are obtained than with standard film. The digital images can also be analyzed with a greater amount of precision and accuracy then photographs. For example, photometric and astrometric measurements can be made from the same image.

Exercise B:

1. Determine either the separation between two stars, the distance between Jupiter and one of its moons, or the diameter of a crater on the Moon.
2. Answer the questions.

To learn more about taking and processing CCD images...

Berry, Richard. Introduction to Astronomical Image Processing. Richmond, VA: Willmann-Bell, Inc., 1991.

Berry, Richard. "Image Processing in Astronomy." Sky & Telescope April 1994: 30-36.

Berry, Richard. "Working in the Digital Darkroom." Astronomy August 1994: 62-67.

Burnham, Robert. "Virtual Sky." Astronomy March 1994: 70-77.

George, Douglas. "Stretching." CCD Astronomy Fall 1994: 8-11.

George, Douglas, Ajai Sehgal, and L. Robert Morris. "Resolution: To The Max." CCD Astronomy Spring 1994: 8-11.

Gombert, Glenn and John Chumack. "Catching Comets with a CCD." Astronomy February 1995: 72-75.

Gilliland, Ronald L. "Details of Noise Sources and Reduction Processes." Astronomical CCD Observing and Reduction Techniques. Astronomical Society of the Pacific Conference Series Vol. 23. Howell, Steve B., ed. San Francisco: BookCrafters, Inc., 1992. 68-89.

Hayes, Brian. "Scanning the Heavens." American Scientist November-December 1994: 512-516.

Kaitchuck, Ronald H., Arne A. Henden, and Ryland Truax. "Photometry in the Digital Age." CCD Astronomy Fall 1994: 20-23.

Meyer, Eric and Herbert Raab. "CCD Astrometry." CCD Astronomy Winter 1995: 20-22.

Newberry, Michael V. "The Signal to Noise Connection." CCD Astronomy Summer 1994: 34-39; Fall 1994: 12-15.

Newberry, Michael V. "Recovering the Signal." CCD Astronomy Spring 1995: 18-21.

Newberry, Michael V. "Dark Frames." CCD Astronomy Summer 1995: 12-13.

Reader Reports. "Capturing Colors with a CCD." Astronomy December 1993: 89.

Reader Reports. "Full Moon Tricolor CCD Imaging." Astronomy June 1994: 81.

Schild, Ralph E. "Coloring the Electronic Sky." Sky & Telescope February 1988: 144- 147.

Skiff, Brian A. "CCD Observing Projects for Amateurs." Webb Society Quarterly Journal No 92. Author's Reprint. April 1993: 10-16.

NAME________________________
DATE________________________
INSTRUCTOR________________

Exercise A1
TELESCOPE VIEWS

object ____________________	object ____________________
app. magnitude ____________________	app. magnitude ____________________
appr. distance ____________________	appr. distance ____________________
telescope ____________________	telescope ____________________
eyepiece ____________________	eyepiece ____________________
magnification ____________________	magnification ____________________
field of view ____________________	field of view ____________________

CCD VIEW (as seen on the computer monitor)

object ______________________
camera ______________________
telescope ______________________
field of view ______________________

NAME________________________
DATE________________________
INSTRUCTOR________________

Exercise A2

TABLE 1. LIST OF IMAGES

	object	image name	exposure	UTC	notes
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

TABLE 2. LIST OF IMAGE CORRECTIONS

image name	correction applied	image name	new image	notes

NAME______________________
DATE______________________
INSTRUCTOR_______________

Questions

A4a. Why does it help to have so many frames to average?

A4b. What types of artifacts are removed during the averaging?

A4c. What are the sources of the defects in the flat-field frame?

A4d. Why does flat-fielding remove certain artifacts?

A4e. Why should you not go past the saturation point?

Exercise B1

object ______________________________

image name ________________________

___________________________________pixels apart

___________________________________arcsec/pixel

___________________________________arcsec apart

Now use the small angle equation to convert the angular separation into a distance. $\boldsymbol{\alpha/206265 = d/D}$ where α is the angular separation in arcseconds (calculated above), d is the actual separation (or diameter) of the object (what you are looking for), and D is the distance to the object. (The distance D will be provided by the instructor.)

NAME______________________
DATE______________________
INSTRUCTOR________________

How does this calculated value compare to the actual value?

Useful conversions:

1 AU =149,597,870km = 92,956,000mi $\cong$ 1.5 x 10^8km $\cong$ 93 x 10^6mi
1 ly = 9.5 x 10^{12}km
1 pc = 3.26 ly

Questions

B2a. If we wanted to image M1, which is about 6 light-years across and 6300 light-years away, which camera and telescope should we use?

B2b. In the following sketches, mark the line(s) representing the calculated and actual distances between the two stars. Why are the distances different in one sketch? (Hint: Draw an eye to represent where we are in space relative to the two stars in each sketch.)