ASTR:4850 - Plate Scales of CCD Cameras

1 Introduction

The purpose of this lab exercise is to measure a key parameter that describes a telescope + CCD camera system. The plate scale in unit of arcsec per pixel is used to translate separations in pixels on an image to angular separations on the sky. We will first calculate the plate scale using a formula based on the focal length of the telescope and the physical size of the pixel, and then compare it with the empirically measured value.

2 Equipment Description

The telescopes are not all identical. This write up assumes that the telescope used is a compact refractor with 80 mm aperture and 400 mm focal length. Depending on the availability of telescopes, you may need to use a different telescope. If so, you may need to adjust the distance at which you place the graph paper/test pattern and the focal length used in your calculations.

As in the previous lab, you will use a StarShoot G3 Deep Space Monochrome Imaging Camera made by Orion Telescopes and Binoculars for this lab.

3 Data Taking and Measurements

We now will attach the camera to the telescope and set up to take images of the test pattern.

- Your telescope should be mounted on a tripod. If not, mount your telescope on a tripod or other suitable mount.
- If you are using one of the compact refractors, you will need to attach a diagonal or extension tube in order to be able to focus. The reflectors don't need this. In the following, we'll assume you are using a diagonal if you are using a reflector read 'diagonal' as 'eye-piece tube'. Slide the diagonal into the telescope and tighten the set screws holding it in place.
- Our test pattern is a piece of graph paper. Measure the spacing between lines on the graph paper and record the value in your notebook.
- You will want to setup the test pattern so that it is perpendicular to the line of sight from the telescope to the test pattern. Usually, it is easiest to tape the test pattern to a wall and then move the telescope and tripod. The test pattern needs to be far enough away that you can focus on it. The compact refractors can focus down to about 4 or 5 meters. The minimum focusing distance for other telescopes may be longer and you may have to move the hallway. If you have one of the other telescopes, discuss the minimum focusing distance with the TA.

- Put an eyepiece into your telescope and focus on the test pattern. Make sure that you can get a sharp image.

- Now we'll attach the camera. Check that the nosepiece adapter is tightly screwed onto the camera. Take out the eyepiece and slide the camera into the diagonal. Tighten the set screw that holds the camera in place. Check that the set screw is tight. Reconnect the USB and +12V cables.

- Start up Camera Studio. Turn on cooling and adjust the exposure as before.

- Once you have a good exposure (White should be at least 15,000 and not more than 45,000) try focusing the telescope. In the capture window click on "Loop" so that you get a continual stream of images.

- The blue and red markers in the Histogram window adjust the gray scaling in the image window. Play with them a bit. You may need to adjust them as you focus. You may even need to adjust the exposure time.

- Our tripods are rather wobbly so they will shake if you leave you hand(s) on the focuser and for a fraction of a second after you take your hand off. When focusing, it is easy to confuse blurring due to telescope motion with blurring due to poor focus. So, each time you adjust the focus, wait for a few seconds for the vibrations to damp out.

- Eventually, you will get a nicely focused image. Note that you can play with the red and blue markers in the histogram window to enhance the contrast in the image window. If focusing just doesn't work for you, get help from an instructor.

- Make a sketch of the apparatus as you have set it up in your notebook. Include the distance between the telescope and the test pattern; measure from the front of the lens which is not the same as the front of the telescope. On the reflectors, measure to the mirror, which is quite far from the front of the telescope.

We now will take some images of the test pattern.

- Verify that you have a nice sharp focus and adjust your exposure time as needed to get high, but unsaturated counts.

- In order to make the analysis easier, we want to get the rows and columns of the CCD lined up with the lines of the graph paper. We can do this by rotating the camera in the diagonal. To provide a reference of the row/column directions, you can either put a crosshair in the Camera Studio image window by clicking on View/Show Crosshairs or left clicking in the image window and then drawing a rectangle (which will be in red). Do one or both of these then go into Loop Capture mode.

- Carefully loosen the set screw holding the camera in place and then gently rotate the camera. Be careful that the camera does not fall off the telescope. Note that you will likely need to wait for vibrations to damp out each time you rotate the camera. Try to get the camera aligned with the lines on the graph paper as accurately as you can.

- Once you are aligned, focused, and have good exposure, stop the Loop Capture mode and do a Single capture. Then save the file using File/Save As. Use a descriptive name and save as a "FIT files" (even though it is odd phrasing). FITS or Flexible Image Transport System is a standard file format used in astronomy for everything from optical CCD images to X-ray event lists. We'll do a lot with FITS files in this course.
- Put some other object (like a pencil or your finger) on the test pattern and take a second image. Save the image with a different file name in the same directory and record the file name. Modify diffimage.py to display the two images and their difference image.

4 Analysis and Results

Now you are ready to use DS9 to analyze your images. You main goal today is to determine the "plate scale" of the lens/camera, i.e. the angular size of the camera pixels.

- Load one of your images into DS9. Do this by starting DS9 and then use File/Open. Use Zoom/Zoom Fit to see the whole image. Use Color/Grey to make the image black and white. You might need to play with the options under the "Scale" menu to adjust the contrast. You can adjust the color scale (mapping of pixel values to colors shown on the bottom of the DS9 display) by using the right mouse button. To move the image around, use Edit/Pan then click on the position you want centered in the display. Click on Edit/None when done. (Clicking on the center mouse button should do the same, but doesn't work on all Windows machines.) When you have the image displayed to your satisfaction, print it out and put it in your notebook.
- We do the horizontal plate scale first. Measure the distance in pixels between the vertical lines with the largest separation visible in your image. (Why should you use lines with the largest separation? Record your thoughts in your lab notebook.) We'll do this by drawing a line between the two bars using DS9 in order to get some practice with DS9. To draw a line do Edit/Region to get into Region mode, then do Region/Shape/Line. Now move the cursor to where you want the line to start (an intersection between horizontal and vertical lines near the left edge of the image), click and hold, move the cursor to where you want the line to end (an intersection between horizontal and vertical lines at the same vertical position but near the right edge of the image), then release. After you draw the line, you can click on the end points and move them. The magnifier in DS9 is a good way to make precise placement. Double clicking on the line will bring up a box with its parameters, including length and angle. The angle should be close to zero (if you got the CCD aligned with the test pattern). Record the distance in pixels and the physical distance on the graph paper. It is convenient to do this by writing on the print out in your lab notebook.
- Calculate the angular separation of the ends of your line using the physical separation and the distance between the test pattern and the lens. Record your calculations and your results.

- Determine the horizontal plate scale for this CCD with this telescope. The plate scale is the number of seconds of arc per pixel. Record your calculations and your results. Estimate the accuracy of your result; what are the largest sources of uncertainty and the magnitude of their effect on your results?
- Repeat the process using a vertical line and calculate the vertical plate scale. Record your calculations and results. Are the horizontal and vertical plate scales the same?
- Compare your result with the formula in section 4.1 of the textbook. Comment on the degree of agreement or disagreement. You might try putting the test pattern at a different distance and doing the measurement again.

You're now done with the lab.