

## Lab 6: Lunar Cartography

(Due: 2017 May 02)

### Mosaic Imaging

#### Field of View

The field of view of a telescope/CCD camera combination depends on the focal length,  $f$ , of the telescope and the overall area of the CCD chip. The focal length is set by the optics of the telescope, in this case by the curvature of the mirror. Think of the size of the CCD chip as seen from the mirror, as shown in Figure 1. A distance  $d$  on the chip subtends an angle  $\theta$ , as seen from the mirror, given by

$$\tan \theta \approx \theta = d/f,$$

where  $\theta$  is in radians. This angle is the same as the angle in the sky from which the rays (blue in the figure) must come to focus at  $d$ . Since there are 206265 arcseconds in a radian, we can determine the *plate scale*,  $s$ , in arcsec/mm, by setting  $d$  to 1 mm, i.e.  $s(\text{"/mm}) = \theta|_{d=1} = 206265''/f_{\text{mm}}$ , where  $f_{\text{mm}}$  is the focal length in mm.

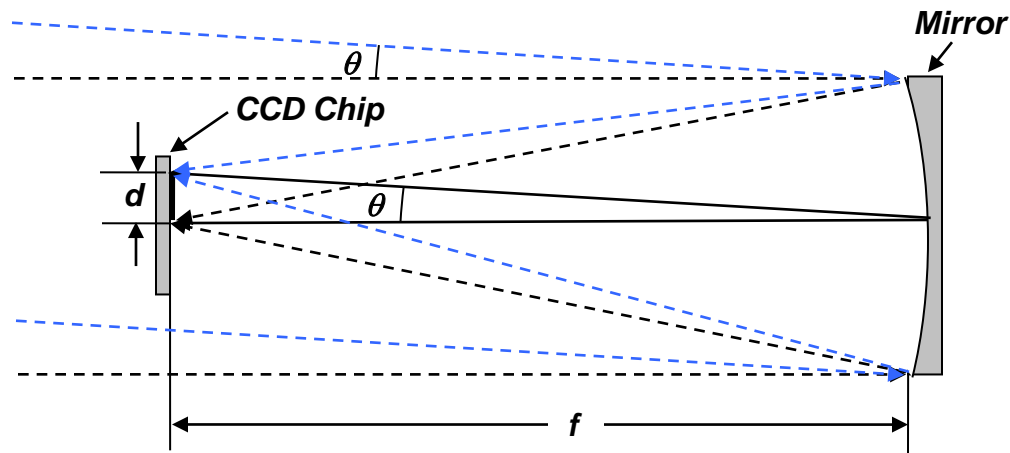


Figure 1

You can see, then, that a long focal length corresponds to higher resolution (smaller  $s$ ). You measured the focal length of the telescope in the first lab, and the pixel size of the CCD was given in the table for the second lab. **Use these values to calculate the angular size of a pixel (arcsec/pixel), and compare with the value you got in Lab 1. Use the number of pixels for the camera, as listed in the table from Lab 2, to determine the field of view of the camera, in arcminutes. Do this calculation in your lab book, and include the results in your report.**

#### Angular Size of the Moon and Need for Mosaic

The Moon subtends an angle of about  $\frac{1}{2}$  degree as seen from the Earth. Compare this with the field of view of the camera, and estimate how many camera fields will be needed in the vertical (declination) and horizontal (hour angle) directions. You will see that more than one camera frame is needed to cover the Moon entirely. We will take several images of the Moon, moving the telescope slightly between images so as to cover the

Moon entirely, and then we will combine the images to make a single, full-disk image of the Moon. To do this, we will make use of a Visual Basic script that I have written, called RasterSequence, which takes a sequence of images, moving the camera between each, to cover an  $n \times n$  frame area, where  $n$  is an odd integer.

### About Mosaics

As shown in Figure 2, below, a mosaic is just a set of partially overlapping images that cover a larger area than a single image would. A successful mosaic requires a significant overlap between the fields. When it comes time to reassemble the images, you can use the overlap to adjust the position and orientation for the best match. MaxIm DL has a mosaic feature that helps with this reassembly.

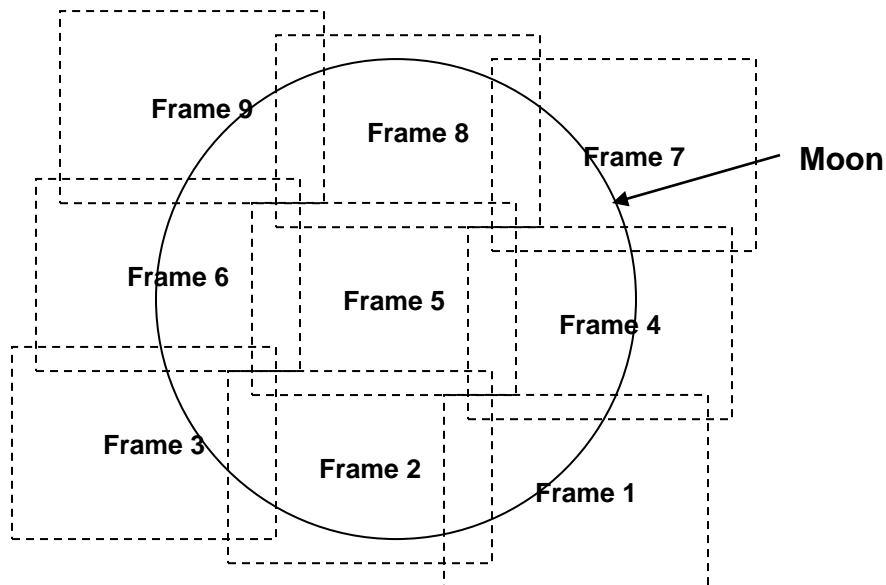


Figure 2

### Procedure for Lunar Imaging

The telescope should already be set to track the Moon, and Cartes du Ciel should be open to show you where the telescope is pointing. To make sure that you are tracking close to the center of the Moon, go to a nearby bright star (within 5-10 degrees of the Moon) and sync the telescope so that the star is in the center of the camera frame. Also ensure that you have the best possible focus. As always, make sure that the camera is at its temperature set point, and is stable. Then send the telescope back to track the center of the Moon. **Write down in your log book the declination of the Moon that Cartes du Ciel gives.** Because the Moon is so bright, the regular color or luminance filters let in too much light to keep the Moon from getting over-exposed. Instead, on the Expose tab, select the H-alpha filter and set the duration of the exposure to the shortest possible, which is 0.1 s. (You can set the exposure time shorter, but it is not really shorter—the minimum camera duration is 0.1 s.) Take an exposure and verify that the Moon is in focus and well exposed. When all is okay, set up a sequence by selecting the Sequence tab and using the options button to set up your directory and the following sequence:

- Type: Light
- Filter: H-alpha
- Suffix: H
- Exposure: 0.1
- Binning: 1
- Repeat: 3

Close the Setup Sequence dialog, type a unique name in the Autosave Filename, and set Start to 1. Do not click Start, however. We will let the RasterSequence script take care of that. We set Repeat to 3 so that later we can select the best of the three images from each position. **Write the unique filename in your log book—this will be the “stem” name for all of your images. Also write down the filter, the exposure time, and repeat count in your log book.**

Now start the RasterSequence script by choosing Run Script... from the File menu, navigate to the directory LX200GPS\Visual Basic Scripts, and click on RasterSequence.vbs. A DOS window will open—just follow the dialog of the script. You can specify the same unique name that you used in the Sequence dialog above. When it comes to the question about the size of the raster, enter 3 twice (one for each dimension), and select 25% for the overlap. This will ensure that there are no gaps when you go to assemble your image. Once you have answered all of the questions, the script will begin to point the telescope and take the images automatically.

After RasterSequence is done and exits, you have one additional, important step to do. We need to know which direction is West. To do this, you will take two more images, and it will be good to have a good section of the lunar limb (edge) in the frame, similar to frame 4 in Figure 2. Set the telescope to point to the spot you want, and open the Scope dialog in Cartes du Ciel. Turn off scope tracking and then *without delay* take two images manually from the Expose tab (exposure time 0.1 s, filter H-alpha), with about 20 s between them, saving each with a suggestive, but unique name like drift1.fit and drift2.fit. **(Write these names in your log book.)** What is happening is that, with the telescope drive turned off, the Moon’s image will drift due to the Earth’s rotation, and of course it will drift to the west, so the direction of drift will determine the direction of west quite accurately. Because your images have an exposure time of only 0.1 s, the images will not be smeared too much due to the motion.

When you are done, you will have 3 images taken at each of 9 different pointings, plus your two drift images. If you had used the name Moon for your Autosave Filename, your images for the first pointing would be called Moon\_1\_1-001L.fit, Moon\_1\_1-002L.fit, Moon\_1\_1-003L.fit, while for the second pointing they will be Moon\_1\_2-004L.fit, Moon\_1\_2-005L.fit, Moon\_1\_2-006L.fit, etc. The first number is the index of the ROW of the image, the second number is the index of the COLUMN of the image. **Make a note of this naming scheme in your log book, using your own unique file name.**

## Calibration

In addition to the data on the Moon, we also need to take the bias and dark frames that we need for calibration. In addition, flat frames will be important for this project, to correct for non-uniform brightness.

## **Image Analysis**

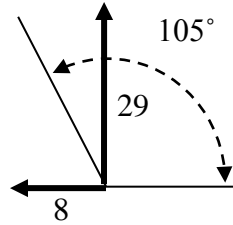
Once you have your data, you will apply the calibration using the calibration wizard, as usual. After your images are calibrated, look at the three images for each pointing to see if one is better than the others. Select the best one for each pointing, or if you cannot see any difference then use any of them. **Write down the number of the ones you chose in your log book, so you can recreate your work if something goes wrong.** Once you have them selected, open the selected images for all 9 pointings in MaxIm DL. Then select New from the File menu and create a blank image large enough to hold your assembled mosaic. With the new, very large image window selected, choose Mosaic from the Edit menu. In the small window that opens, in the drop-down list choose the center image (\*\_2\_2-\*) and place it in the center of your large window. You place it by clicking and dragging with the mouse. When you have it where you want, select “Blend” to add it to the image. Now do the same with the image to the right of the center one (\*\_2\_1-\*), except this time place it so that the overlapping portion is exactly positioned to match the center image. You may need some practice with this. Once you get it close, you can click “Snap” to make it automatically snap into location, but beware that it might fail. After you have it positioned, select “Blend” to add it to the mosaic. Continue these steps with the other images until all 9 are added to form one complete and well-aligned image. Finally, crop the image using Crop from the Edit menu, to clip off the edges and create a more-or-less square image. Save your final mosaic image with an appropriate, unique name.

## **Photoshop**

### **Finding the drift angle:**

Next we will use the two drift images to determine the drift angle, which specifies the direction of West. The easiest way to do this is to open Photoshop CS2 and drag the two drift images (one at a time) into the Photoshop window. This will open a plugin called FitsLiberator, which you can use to read in fits files. When you are satisfied with the inputs, load the image and repeat for the second drift image.

Now in Photoshop CS2, select the second drift frame and type Ctrl-A (select all) and Ctrl-C (copy), then click on the first drift frame and type Ctrl-V (paste). You will now have both frames in the same window, but in different layers. In the Layers window, change Normal to Multiply, so that you can “see through” the top image. Important: Set the zoom to 100% (Actual Pixels). Now using only the arrow keys, move the bottom image until it perfectly overlays the top image, carefully counting the number of arrow taps in  $x$  and  $y$ . Hint: if you find that it is difficult to count because there are so many arrow key presses, note that at 25% zoom each arrow press moves 4 pixels, at 50% zoom, 2 pixels, etc. **Write these numbers down in your log book, with arrows indicating the direction you had to move the image, as in the drawing below:**



In this case, the shift was upward in  $y$ , which is positive, but to the left in  $x$ , which is negative. The total shift, in pixels, is  $\sqrt{x^2 + y^2}$ . The angle of the shift, then, is found by the arctangent, i.e.  $\text{atan}(29, -8) = 105.4$  degrees. Once you have the angle calculated, use Rotate Canvas from the Image menu, and type in the number (105.4 CW in this example) to place the drift direction exactly to the right (positive  $x$  direction). This is west in “Earth” coordinates. If the Moon is a crescent, it may not be vertical! You will rotate your final image later to align it to “Moon” coordinates. Test your angle by using the left/right arrow keys to shift the bottom image. You should be able to line up the rotated edges of the frames again using only the left/right arrow keys, without touching the up/down arrows. **Write your angle and your total shift, in pixels, into your log book. A labeled drawing such as the one above is an excellent way to record this information.**

#### **Determining the lunar image scale:**

We will now determine the scale (arcsec/pixel) of your images. The easiest way to do that is to use the drift measurement and use the fact that the Earth rotates once in 24 h. The rate of rotation in terms of angular distance on the sky is related to the cosine of the declination of the Moon. Say the Moon is at  $+10^\circ 20'$  declination and you let the Moon drift for 20 s. At the equator, the Moon would drift  $15^\circ/\text{hour}$ , but at this declination the Moon will drift  $(15^\circ/\text{hour}) \cdot t_{\text{hour}} \cdot \cos(\text{dec})$ , where  $t_{\text{hour}}$  is the total drift time, in hours. If your drift time is 10 s, the total drift would be

$$15^\circ/\text{hour} \cdot (20\text{s}/(3600\text{s/hr})) \cdot \cos(10.33) = 0.082^\circ = 295 \text{ arcsec}$$

You already measured the drift in pixels, so divide by that to determine the image scale (arcsec/pixel). **Write this number in your log book, and compare with the number you obtained from the first section of this Lab.**

#### **Read in your mosaic image:**

The final step is to read your mosaic image into Photoshop CS2 and orient it with Earth-west to the right. Drag and drop your mosaic image into Photoshop to open the FitsLiberator dialog. For intensity scaling, we are going to use square-root, which usually does a nice job of setting the brightness scale for the Moon. Also adjust the black point and white point to give maximum contrast without clipping. Check the 8 bits/pixel checkbox. When you are satisfied, load the image and rotate it by the angle you found from the previous step. You may want to further adjust the brightness scale using menu item Image/Adjustments/Levels... Once you have your final image, change to 8 bits/channel RGB by selecting Image/Mode/ and setting the appropriate menu items.

**Now measure the size of the lunar disk, in pixels, using the Info window and write**

**down the size in your log book.** Finally, compare your image with the lunar map (see the course syllabus web page, links near the bottom), and flip the image if necessary to bring north to more-or-less the top. As before, any crescent will not be perfectly vertical. You will rotate it further in a moment. Save the image using Save As... from the file menu, saving it as a PSD file. Be careful not to save it as FITS, or you may overwrite your original mosaic image.

## Lunar Cartography

The goal of this lab is to overlay onto your image an accurate grid of lines of longitude and latitude in lunar (selenographic) coordinates. The first step is to obtain some “physical ephemeris” information about the Moon for the date and time of your observations, using a very nice web site called Calsky. Go to [www.calsky.com](http://www.calsky.com), select Moon and Physical Data, enter the date and local time corresponding to your observations in the controls, and click Go. You will be presented with data like this:

Moon

Ephemeris for Physical Observations:

Date	Mag- nitude	<b>Dia-</b> meter	Flatt- ening	<b>Northpol</b> PosAngle	<b>Open-</b> Angle	<b>Centrl</b> Merid.	Sub-Solar-Point Lon	Sub-Solar-Point Lat	Sub-Solar-Point PosAngl	Phase	visible from	visible to
	mag	'		o	o	o	o	o	o		hh.h	hh.h
2006 Feb 12	-12.7	<b>29.43</b>	1.000	<b>21.6</b>	<b>-4.5</b>	<b>1.0</b>	-1.0	2.4	356.4	1.00	17.3h-	7.5h

Where the numbers I have indicated in bold are the ones we will be using. The numbers we need are the Diameter, Northpole PosAngle (P-angle), and Open Angle (b-angle), Central Meridian value. The above numbers are for 2006—your numbers will be different! If the Northpole PosAngle is greater than 180 degrees, convert to a negative angle, (i.e. an angle of 343.7 degrees would be converted to  $(-343.7 + 360 = -16.3$  degrees). Convert the diameter to radius, i.e. 14.71 in the above example.

## Making a grid using IDL

You can make a grid in IDL using a routine called Stonyhurst, using the commands:

```
plot, [-17, 17], [-17, 17], /nodata, /iso  
stonyhurst, -4.5, 21.6, 14.71, CM=1.0
```

where the first statement simply makes an empty box in which to plot the disk grid, and the second statement actually plots the grid (with numbers appropriate to the example above). The first argument to Stonyhurst is the b-angle, the second is the P-angle, the third is the radius, and the CM argument is the central meridian angle. Make the plot window nice and big (replot if necessary), then make a screen shot, and paste it into a new window in Photoshop CS2. Crop the image so that only the grid (without the plot border) remains in the image.

In Photoshop CS2, use Image/adjustments/invert to convert it to black lines on a white background. Measure the grid diameter, in pixels. We need to adjust it to the same size as our Moon mosaic image. Write down the number of pixels, and compare it to the number of pixels you wrote down for the solar disk. If your disk diameter was 665 pixels, say, and the grid diameter is 720 pixels, then we need to resize (shrink) the grid by a factor  $665/720 = 0.9236$ , or 92.36%. Select the grid by using Color range... from the select menu, and set the slider to 100 or so. A “marquis” border will appear around the grid. Now resize by selecting Transform/Scale from the edit menu. Type in the 92.4 in the X size box, and click the link icon to make X and Y scales equal. Click the check

mark. Now type Ctrl-C (copy), and in your solar image window, type Ctrl-V (paste) to paste in the grid. Now you can move the grid around to fit the disk (you should not need to resize if you did your scaling correctly above).

The last step is to rotate the image/grid combined image to correct for the P-angle. Use Transform/Rotate from the Image menu and type in the P-angle to orient the grid vertically. Your image is now in “lunar” coordinate orientation. When you are happy, save the disk with the grid overlay by selected “Save for Web...” from the file menu, saving it as a GIF file. After you save your image, also save the PSD file by selecting “Save” or “Save As...” from the file menu, since you will need this if you need to do further editing.

**You will print a copy of this image for your report.** Now, compare your work with an actual moon map by going to the link called “Moon map” on the syllabus page (or go to <http://ralphaeschliman.com/luna/lnslamasm.jpg>). Compare the grid there with the overlaid grid on your image, checking to see where grid lines cross recognizable lunar features. In your report do a self-evaluation of how well these two agree, and speculate about reasons for any differences seen. It might be useful to zoom in on similar parts of your image and the lunar map, and compare them side by side in image form. How accurate is your result?

### ***Bulletized Synopsis***

#### **Purpose: Learn about mosaic imaging and overlay a coordinate grid on a Moon map**

- Take a raster sequence of images of the Moon, as well as a pair of drift images.
- Put the images together into a single-image mosaic.
- Correct the orientation of the mosaic based on the lunar drift images, to orient with respect to Earth coordinates.
- Create a coordinate grid of lines of lunar longitude and latitude, based on lunar physical data.
- Overlay the grid, and orient with respect to Moon coordinates.
- Compare the resulting lunar map with a published map.