Lab 6: Solar System Imaging
(Due: April 30, 2019)

Webcam Imaging

The CCD cameras we have been using up to now are expensive, cooled cameras built specifically for astronomical imaging of faint objects. However, CCD cameras are found in many devices, including inexpensive webcams intended for the mass market. The main differences in use of these cameras are that they read out at video rates (giving a "motion picture"), they have no ability to take a "time exposure," and they have an amplifier that can be adjusted to amplify the signal after readout from the chip. It is best to avoid or minimize use of the amplifier, since it leads to an increase in noise.

We will use the ToUcam 2 webcam, by Philips, which has a 640 x 480 pixel chip with extremely small pixels (5.6 μm). It is this small pixel size that makes it ideal for imaging the Sun, Moon, and planets, but it can only be used for such bright objects since it is not sensitive enough, and cannot do time exposures, to allow its use for faint objects.

In addition to the camera and control program, this lab project will introduce two new, free software programs, Virtual Dub and Registax 2, which will make our imaging experience easier and result in sharper images.

You should plan to do at least two of the solar system targets
- the Sun in H-alpha, using the H-alpha telescope (will have to be done in daytime!)
- the Moon
- Saturn

Sun in H-alpha

We have a small telescope that can be mounted on the 10" telescope in place of the finder. This telescope is equipped with a hydrogen-alpha (Hα) narrow-band filter, which brings out the contrast and allows ordinarily invisible details to be seen. Without this filter, the Sun would be too bright to image at all. You will use the webcam to take images of a part of the solar disk, scan the telescope across the disk to capture the entire disk, and then use image processing software to sharpen the images and assemble them into a full-disk image of the Sun. Once the full-disk image is obtained, you will create an overlay a grid of longitude and latitude on the Sun and compare it with similar images available on the web.

The Moon

The Moon can be imaged directly through the 10" telescope, but because of its very large angular size (½ degree) and the very small field of view of the webcam, you will only be able to image a small part of the Moon (although at high resolution). For comparison, you will also take a mosaic of the Moon using the larger CCD camera, which will allow you to construct a full-disk image. You will create an overlay grid for this image, also.

Saturn

Since Saturn is near its closest approach to Earth (opposition), it is about as large as it ever appears in the sky. Using the webcam, you will take a video of Saturn and process it using Registax 2, to create a sharp and beautiful color image of the planet.

Procedure for Solar Image

The telescope should already be set to track the Sun, and Cartes du Ciel should be open to show you where the telescope is pointing. You should be able to use the hand controller to position the Sun where you want to begin. Adjust the camera control program so that the image is at its best focus and contrast. Use the black-and-white setting for best contrast. Before taking your actual data, position the Sun so that you can see most of the equatorial part, turn off the tracking using the Cartes du Ciel telescope panel, and then start recording. Let the image drift for 10-15 seconds, so that it is clear what angle the drift takes. The drift, of course, is due to Earth rotation, so the solar image will drift east to west and by tracking features we can directly measure the angle of west on the Sun. Stop recording, start tracking again and reposition the telescope. In your log book, make a sketch of the frame and the motion direction. Important: note the date and time of your videos in your log book, since there is no FITS header to keep track of that for you. Take a series of short (10 s) videos, with tracking on, positioning the Sun for each one, so that you cover the entire Sun. Make sure that you do not change the angle of the camera while taking the images. It should only require 4-6 videos to cover the entire disk. Write down the names of the files in your log book. If you have taken more than a few minutes to take your videos, you may want to quickly repeat the drift scan so that later you can measure to see if it has changed.

Virtual Dub

You will now use a handy program called Virtual Dub to select the best frames from your videos. Virtual Dub is very easy to use, and allows you to select part of a long movie, save it out as a separate file, and then use it for subsequent processing. Start Virtual Dub and select File/Open from the menu, then navigate to your movie (.AVI) file and open it. The first frame of the movie will be shown in the window. You can run the movie by clicking on the play icon (the right arrow at the bottom row of buttons), or you can position the movie at any frame using the slider control above that row of buttons. The goal is to select a part of the movie where there is little motion or jerkiness—a total of 30-60 frames is usually plenty. To mark the selection, move the slider to where you want to start, and click the "Mark in" button (next to last button in the row of buttons). Then move the slider to where you want to end, and click the "Mark out" button (last in the row). Now select File/Save As AVI… from the menu, and save the new file under helpful name. Repeat for other sections of the video, or for the other videos, until you have enough to cover the entire disk. Write down the names of these new files in your log book.

Registax 2

Once you have your selected solar video clips, open Registax 2 and open the first one by clicking Select Input on the "Input" tab and navigating to your files. The program will show the first frame of your video, and when you move the mouse you can position a

small square box. If there is a clear, contrasty feature on the Sun, click on it with the box cursor. It is possible to change the size of the box if desired. Registax 2 will then put you on the "Aligning" tab and open a couple of windows. You can either click the Align button (near the bottom right), or the Align and Stack button. The program will then read in each frame of your video and shift each image to align with the first one. This may take a couple of iterations. After the alignment, the program reorders the frames in "image quality" order. The Stack tab allows you to adjust which frames you want to use, and then stacks the frames to create a single image made up of an average of the best frames in the video. Click the stack button, and then write down the number of frames that were stacked. Finally, the Wavelet Processing tab allows you to sharpen the image. It is this last stage that really improves the result. When you have a final image that you like, write down the wavelet settings for 1-6, save it as an 8-bit BMP, then repeat the process for the other images you saved in the previous section. Write down the names of your final images in your log book, indicating the number of frames stacked, and the wavelet settings.

Photoshop CS2

Finding the drift angle:

First we will determine the drift angle from your drift video. The easiest way to do this is to open both Photoshop CS2 and Virtual Dub, and open the drift video in Virtual Dub. Position the video at a convenient point to use as the start of the drift, and click both "Mark in" and "Mark out" on the same frame. Then select Copy from the Edit menu. In Photoshop CS2, select New from the file menu, click okay (you can change the name or leave as untitled), and then select Paste from the Edit menu. Repeat for a frame near the end of the drift video.

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. 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. Write these numbers down in your log book, with arrows indicating the direction you had to move the image, as in the drawing below:
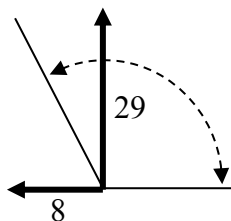
In this case, the shift was upward in y, which is positive, but to the left in x, which is negative. The angle of the shift, then, is found by the arctangent, i.e. atan(29,-8) = 105.4

$105°$

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. 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.

Assembling the images:
The final step is to assemble your individual images into a full-Sun image, for which we also use Photoshop CS2. The basic procedure is to read in all of the frames, increase the "canvas" size (from the Image menu) of one of the images to make room for the full Sun, and then cut and paste the individual frames into the enlarged one. You can then slide the images around to align them, using various tricks that will be demonstrated to you. You will erase edges of some images to remove "glitches," and possibly adjust the brightness to balance them. Once you have your final image, measure the size of the solar disk, in pixels, using the Info window and write down the size in your log book. Finally, rotate and flip the image according to the drift angle you measured, to place north up and west to the right. Save the image using Save for Web… from the file menu, saving it as a GIF file.

Making a grid using IDL

You can make a grid using a routine called Stonyhurst, but first we need to know the parameters of the Sun for the day and time you took the videos. Go to www.calsky.com, select Sun and Physical Data, enter the date and local time in the controls, and click Go. You will be presented with data like this:

```
Sun


Ephemeris for Physical Observations:
Date    Mag-  Dia- Flatt- Northpol Open- Centrl  Sub-Solar-Point   Phase  visible
     nitude meter  ening PosAngle Angle Merid.  Lon   Lat PosAngl        from    to
2006    mag    '          o       o     o       o    o     o         hh.h  hh.h
Feb 11 -27.0  32.41 1.000  343.7   -6.7  43.7                         7.1h-17.7h
```

The numbers we need are the Diameter, Northpole PosAngle (P-angle), and Open Angle (b-angle), which I have indicated in bold. Convert to radius (16.2 in the above example), P-angle between –180 and 180 (–343.7 + 360 = –16.3 in the above example). You will then make a relatively large plot of the grid, using the commands:

```
plot,[-17,17],[-17,17],/nodata,/iso
stonyhurst,-6.3,-16.3,16.2
```

where the first statement simply makes an empty box in which to plot the disk grid, and the second statement actually plots the gird. The first argument to Stonyhurst is the b-angle, the second is the P-angle, and the third is the radius. Make the plot window nice and big, 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 size, in pixels. We need to adjust it to the same size as our Sun 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 size was 665 pixels, say, and the grid size 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 "solar" coordinate orientation. When you are happy, save the disk with the grid overlay by selected "Save for Web…" from the file menu. After you save your image, also save the PSD file by selecting "Save" or "Save As…" from the file menu.

You will print a copy of this image for your report. Also go to http://www.solarmonitor.org/index.php and print a copy of the H-alpha image for the same day as your image, to compare. Put this image side-by-side with yours. Do they agree? If not, what went wrong? If so, feel proud.

Procedure for Lunar Image

This section will only describe differences from the above procedure, since some of the steps are the same. The main difference is that the images of the Moon will be taken through the 10" telescope itself, and so the images will pertain only to a very small area of the Moon. It gives a nice closeup view, but to make a mosaic of the entire Moon would take 60 or more "pointings." Instead, we will focus on particular areas chosen by you for their interesting features. You will first locate the area you wish to image, and then do a small mosaic of about 6 pointings around that point. Write down the declination of the Moon as given by Cartes du Ciel. You will also do the drift measurement, turning off the drive motor for a fixed length of time, in order to determine the direction of west. The entire procedure is exactly the same as for the solar images, above, including the data taking, the running of Virtual Dub, and the running of Registax. You will also combine the images in Photoshop in the same way, orienting them with the rotation angle that you measured using the drift data.

The lunar grid requires a couple of changes.

Determining the lunar image scale:
First, you need to determine the scale (arcsec/pixel) of your image. 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° 20' declination and you let the Moon drift for 10 s. At the equator, the Moon would drift 15°/hour, but at this declination the Moon will drift $(15°/hour)*t_{hour}*\cos(dec)$, where t_{hour} is the total drift time, in hours. If your drift time is 10 s, the total drift would be

15°/hour*(10s/(3600s/hr))*cos(10.33) = 0.041˚ = 147.5 arcsec

So you can easily measure the drift in pixels, and determine the image scale (arcsec/pixel). When you find the drift angle in Photoshop, also determine the total drift (sqrt($x^2 + y^2$)), and find the image scale.

Creating the overlay grid:

When you run IDL, the lunar overlay grid is done slightly differently from the solar one. For one thing, the "central meridian" of the Sun's disk is always considered to be zero, but for the Moon it can change slightly from zero due to lunar libration (the fact that the Moon's orbit is not exactly circular). You will use Calsky, as before, but selecting the Moon to get its Physical Data. The result may look something like this:

```
Moon

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

where now the Central Meridian value (highlighted in bold) will also be used. When you create your grid in IDL, use the commands

```
plot,[-17,17],[-17,17],/nodata,/iso
stonyhurst,-4.5,21.6,14.97,CM=1.0
```

where a new argument CM=1.0 is used. You will, of course, set CM equal to whatever the Central Meridian value is on the date of your observations.

You will then follow the procedure outlined above to screen capture and scale the grid, but the scale will be determined by measuring the pixel height of the grid—say it is 720 pixels, and noting that this is 29.43' (using the number above for the lunar Diameter), so the grid scale is 29.43' * (60arcsec/arcmin)/720 pixels = 2.45 arcsec/pixel. If your image scale is, say, 0.95 arcsec/pixel, you would enlarge the grid by a factor 2.45/0.95 = 2.58. Note that the scaled grid will be very large, but cut and paste it anyway.

Now, to figure out where the grid should be shifted, go to the link called "Moon map" on the syllabus page (or go to http://ralphaeschliman.com/luna/lnslamasm.jpg), find the place on the map corresponding to your image, and compare the grid there with the overlaid grid on your image. It should be possible to simply shift the grid and have it match what you see on that Moon map.

Save the image as before, and print a copy for your report.

Procedure for Saturn Image

For this image, all we are after is a pretty picture. Simply put the image on Saturn on the webcam frame, near the center, and take a video of 10 s or so, with appropriate focus and image brightness adjustment. It is kind of fun to do a more sensitive exposure, too, overexposing the planet so that the moons show up. Do the Virtual Dub selection, if necessary, and the Registax analysis. Be sure to select RGB analysis so that your image comes out in color. Make the best image you can, save it, and print it for your report.

Bulletized Synopsis

Purpose: Learn about webcam imaging and analysis of solar system objects

- Get the Sun focused in the H-alpha telescope, with brightness level adjusted for a good exposure.
- Take a video with the tracking turned off, to measure the direction of drift (west) on the image.
- Take videos of up to 6 pointings to cover the entire disk.
- Select the best parts of the videos with Virtual Dub and stack and enhance them in Registax 2.
- Combine them into a single, mosaic image, and overlay the image with a solar grid at the proper orientation and scale.
- Repeat the procedure for a (smaller) area of the Moon.
- Make a "pretty picture" of Saturn.