Term Paper for PHYS 490

Special Topics

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CCD Astrophotography

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Basic CCD Camera Operation

The camera that was used throughout the course of PHYS 490 was a model ST-6 professional CCD (charged coupled device) imaging camera which is manufactured by the Santa Barbara Instrument Group, California. The camera is accompanied by software designed specifically to compliment the ST-6 CCD camera. This is a basic “crash course” camera and its software’s operation.

The telescope onto which the ST-6 camera is to be mounted must first be properly focused in order for the images captured by the camera to have proper resolution. This was done in this course by using an eyepiece for the camera that had a marking on it which would indicate the depth the camera could reach into the camera. Once this eyepiece was inserted to the marked distance, the telescope was focused to produce the crispest image resolvable to the eye. With this complete, the telescope is now properly focused for the camera and the camera can now be mounted onto the telescope. It is advisable to already have a motor attached to the telescope to reduce the formation of diurnal circles and to focus the camera on the object one wishes to take an image of. The mounting process is very simple—insert the camera as far as possible and tighten the screws on the camera to secure it to the telescope.

Now, the camera must be properly connected to the camera’s CPU (central processing unit) which entails ensuring that the cord on the camera is properly inserted into the port labeled for input. The power supply must also be supplied through this way as well as the output cord that transfers data from the camera’s CPU to the computer on
which the ST-6 software is installed. Once all these connections are made, the camera is now physically ready to take CCD images.

Before an image can actually be taken, the ST-6 software must be booted up on the computer that is receiving the output from the camera. Once the software is up and running, it will attempt to establish a communication link with the camera. If there are no difficulties in doing this no error message will appear, however, if the communication link cannot be established, an error message will appear. If this happens, check that the connections with the camera, power supply, and CPU are all in place.

Once any error messages are resolved, the set point temperature must be established—the lower the temperature of the actual CCD, the less intrinsic noise is created to pollute the CCD image. There are methods to help eliminate any intrinsic noise but that will be discussed later. After experimenting with different temperatures, it has been found that a set point temperature of –25 degrees centigrade yields the least noise with the greatest efficiency. The lowest temperature attainable by the camera is -40 degrees centigrade.

The observer name(s), aperture of the telescope, and focal length of the telescope should also be preset through the edit parameters function in the utilities pull down menu so that functions such as the arc diameter of an object can be accurately determined.

Now, with all of the telescope specifications programmed into the software, the communications link between the camera and the computer established and the camera properly focused, a CCD image can finally be taken. Select the grab option from the camera pull down menu and select an exposure time and make sure to specify that it is a light image. The camera then takes the image, digitizes it and sends it through the CPU
to the computer for the image to be processed into a visible representation of the object.

Once this is done, select the X hairs option from the menu accompanying the image so that the focus and exposure can be evaluated. If the pixel values for the edges of the subject of the image have a sharp drop off, this signifies that this object is in focus. If the brightest part of the images has a distinct maximum value then the exposure time is good. Even if the image passes these tests, it may still be desirable to adjust settings for other aesthetic reasons.

Also, when on MCGA mode, the background value and range of the pixel values can be changed so as to better define the object. Technical limitations of the camera (such as blooming and artifacting) may become more prominent in this process but objects with a very low luminosity will become more visible. My personal advice, if in doubt as to whether or not there is anything else in the image that cannot be seen, select the negative function from the menu accompanying the image. This makes dim objects much more obvious.

Now, with the image taken, the intrinsic noise should be eliminated—at least to a great extent. Save the current image and then select the grab function again, set the exposure time to the same as the previous image and also specify that this is a dark image only. A dark image is an image that is not of anything but the noise involved with the CCD. Save this image as well. Then, from the file function, load the light image you had saved, then select the dark subtract function from the utility pull down menu and specify the dark image that was just taken. What this does is digitally subtract the pixel values of the dark image, which is just noise, from the light image. This is a viable method of
eliminating the noise since each CCD pixel has a characteristic noise value that is relatively static from image to image.

Some of the more sophisticated analysis functions that the software can perform, among others, is magnitude comparisons and arc diameter of objects. The magnitude option allows the magnitude of an object to be determined from either a dark portion of the sky or by comparing it to another star in the field. This is done by taking the cross hair to a dark section of the sky in the field of view (or another star that is wished to be compared) and pressing B. This sets the magnitude reading to 99. Move the cross hairs to the desired star in which the magnitude is to be measured or compared to and the magnitude reading will appear. The arc diameter of an object can be determined by placing the cross hairs on an edge of an object and then selecting set position. When the cross hairs are moved, the distance between them are read in arc seconds and displays as the numbers beside SEP.

Once a session of observing is done for the night, the camera must be shut down and allowed to warm up gradually so as not to damage the CCD. Also, before exiting the program, make sure that all images have been saved. (It really sucks to lose an image that took so much effort to “grab.”) Then the camera is to be dismounted from the telescope and properly placed back into the cushioned box used for storage.
Programming to Analyze ST6 Images

I programmed with Microsoft QuickBasic version 4.5 so that the pixels of an ST6 image (the image taken by this model of CCD camera) can be evaluated. The two programs that I wrote for this course was one that output the individual pixel values for the uncropped, uncompressed ST6 image (q.v. Appendix A) and another one that calculated the average pixel value for an entire ST6, uncropped and uncompressed image (q.v. Appendix B).

An ST6 image has 2049 bytes of header information which includes such things as telescope aperture, focal length, observers name, exposure time, etc. The actual image information begins at byte 2050. Each pixel is stored in two eight bit sections and the pixel value can be calculated from the first section plus 256 times the second section. The image is composed of 242 rows of pixels and 370 columns of pixels yielding a total of 90,750 pixels.

Each program used “for” loops to tally up the pixel value and the only big difference between the program that outputs the individual pixel values and the program that outputs the average pixel value is that the program that outputs the average pixel value adds each pixel value to an index that was originally set to 0 and then the index was divided by 90,750.

Please refer to the appendix for a hardcopy of each program’s code.
Discussion of Images Taken

Before the discussion is begun, the meaning of the file names described in this section should be explained. Take the file name 24NOV018.ST6—the numbers before the alpha characters represent the day of the month in which the picture was taken, the alpha characters are an abbreviation for the month in which the pictures were taken, the next two numbers represent the sequential order of the picture for that date (i.e. 01 means the first picture for that date, 02 means the second picture for that date, etc.) and the last number represents the last digit in the year that the picture was taken, assuming the first other three are 199_ (I guess this is yet another complication that the Y2K bug will cause).

Polaris

The images taken of Polaris on the night of November 24, 1998 in Dr. Greg Latta’s back yard. The conditions were initially poor with large cirrus cloud cover but dispersed as the night progressed. Once the clouds departed, we commenced on taking these CCD images of Polaris (q.v. floppy disk accompanying this paper).

Three images were taken of Polaris. 24NOV018.ST6 is an overexposed image of Polaris with an exposure time of 1 second. The image is dark subtracted. The second image of Polaris, 24NOV028.ST6 is also overexposed at a quarter of a second but is not dark subtracted since I overlooked taking a dark image at this exposure. Finally, 24NOV038.ST6 is an image of Polaris that is in good focus at 0.1 second exposure.
Again, this image is not dark subtracted since I overlooked taking a dark image at this exposure as well.

\textit{Jupiter}

There were five images taken of Jupiter since the exposure time is touchy when dealing with such a bright object. Therefore, these images reflect experimentation with exposure times in order to find the optimal exposure.

The first image, 24NOV048.ST6, is a 0.1 second exposure and shows Jupiter overexposed. Again, since no dark image was taken for this exposure time, this image is not dark subtracted. The next image, 24NOV058.ST6, shows Jupiter glaringly overexposed (surprise!) and this image is dark subtracted. 24NOV068.ST6 is an exposure at one half second, is still overexposed and dark subtracted.

The best image taken of Jupiter that night is by far 24NOV078.ST6—a 0.01 second exposure that I have zoomed, dark subtracted and adjusted the background so that the moons of Jupiter could be made visible (but the blooming effects were enhanced in the process). At that time and date, Ganymede is eclipsing Europa as illustrated in both the computer simulation from Astronomy Lab 2 and the CCD image (q.v. Appendix C). Also, using the set position function in the camera’s complimentary software, I determined the angular diameter of Jupiter to be 116.98 arc seconds.

The last image that was taken of Jupiter that night was 24NOV088.ST6 which has pretty good focus at an exposure time of 0.03 seconds. This image is dark subtracted.
At first, when these next two images were taken, it was unknown exactly what cluster was being digitized so Dr. Latta left it up to me to identify it but I will get into that later.

The first image, 24NOV099.ST6 is a 5 second exposure of the cluster in Auriga and is dark subtracted. Unfortunately, the cluster is cut off because the telescope wasn’t centered on it properly. The next image, 24NOV109.ST6, is a also a 5 second exposure and is nicely centered and focused image of the cluster and this image is also dark subtracted as pictured in the accompanying illustration.

I determined what this cluster in Auriga was M36 by using Burnham’s Celestial Handbook and matching this cluster to the one listed in the handbook around the same position as this one was and then I refined which cluster this actually was by matching it with the illustration in the handbook to that of M36.
The Leonid Meteor Shower

In the early morning of November 17, 1998 (between the hours of 3:00 and 5:00 am EST) Nikki Huffman and myself went to the near top of Dan’s Rock, MD to take photographic images of the Leonid meteor shower. The Leonids were to peak at approximately 3 pm EST which meant the peak of the shower would not be visible to us. However, the show was still quite spectacular.

The meteors didn’t actually originate out of the constellation Leo but when the trails of the meteors are traced backwards they intersected in the constellation of Leo. The zenithal hourly rate I would approximate to be between 15 and 20. The luminosity of these meteors were great when compared to those meteors that occur at the peak of the Perseids in late summer. Some of these Leonid meteors were fireballs the lit up the night sky light a camera flash. The ZHR for fireballs was about 2-3 per hour.

Most meteors passed through the constellations of Orion and Cassiopeia (see accompanying illustration with a meteor passing by Cassiopeia) so this is where I concentrated taking photographing. I used Kodak Gold Max 800 speed film, a 28 mm wide angle lens and a fixed tripod camera set at f 1.9. Two of my best photographs can be viewed on the Cumberland Astronomy Club web page at [http://antoine.fsu.umd.edu/phys/luzader/cac/fixed/fixed.shtml](http://antoine.fsu.umd.edu/phys/luzader/cac/fixed/fixed.shtml)
Besides getting some very nice meteor pictures, I also got several nice constellation pictures of Orion, Lepus, Sirius and Cassiopeia, got images of the some small diurnal circles rotating around Polaris, and got a decent image of star trails that define the celestial equator (q.v. Appendix D).
Proposal for a research project to be carried out in PHYS 400 and IDIS 493 (Honors Thesis).

Variable Star CCD Photometry and Analysis

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Submitted in fulfillment of requirements for PHYS 491 and the prerequisites for IDIS 493.

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Abstract

My research will focus initially on the techniques required to properly observe and analyze a variable star. The technique as planned includes selecting a variable star to observe and selecting a constant magnitude star in the same star field as the variable star, and observing the frequency of the variable star by taking CCD (charge-coupled device) images though the CCD camera. The software that accompanies the camera I plan to use has utilities that will assign the variable star a comparative magnitude with respect to the constant magnitude star I select as my reference.

First, a short period star (preferably a member of the Cepheid populations) will be observed and its light curve will be plotted in order to refine my photometry techniques. A longer period variable star (perhaps of the Beta Canis Majoris group) and/or an eclipsing binary system will be observed, weather permitting. Once the observations are complete, a Fourier analysis of the light curve will be performed in order to reveal any periodicities that are not obvious from the light curve and a hypothesis formation will be attempted in respect to what is causing the varying luminosity of the variable star.
**Introduction**

Variable stars are stars that vary in luminosity over a period of time which can range from several hours to many days and each star has its own characteristic period.\(^1\) The purpose for the research being proposed here is to observe a variable star and analyze the luminosity variation over the star’s period. CCD photometry will be implemented due to its sensitivity and convenient digital format. The data collected will be processed first by the CCD camera’s software in order to plot the star’s light curve and then this light curve will undergo a Fourier analysis to analyze the periodicities of the light curve. From this Fourier analysis, a hypothesis will be attempted in order to account for the luminosity variations.

**Background**

A CCD camera detects photons and these photons induce a charge which is then recorded and then interpreted by the camera to produce a digital image. The quantum efficiency (the photoelectric effects that induce a charge on the CCD) of CCD cameras is extremely high and thus makes the camera extraordinarily sensitive to the few photons that have traversed the light years and penetrated the earth’s atmosphere. Along with the camera’s sensitivity, CCD cameras are very linear and, by this, can measure light intensity accurately.\(^2\) These two features make CCD astrophotography preferable over traditional silver astrophotography. Figure 1 illustrates the power of the CCD camera by
showing an image of the horse-head nebula which is very faint but this 900 second exposure can resolve the nebula and stars around it well.

**Procedure**

Since a CCD camera is an area detector, it can cover a decent fraction of the telescope’s field of view and can therefore observe more than one star. Therefore, a choice field of view would be one that contains a variable star and a constant magnitude star so that both are visible in the image. Using this comparative method allows for atmospheric variations from one night to another to be all but eliminated. Since the CCD has an intrinsic “noise” involved with it, a dark frame (a frame that is the same temperature and exposure time as the image being processed but not exposed to any photons) must be digitally “subtracted” from the actual raw image in order to eliminate the noise in the picture. This is done using the software that accompanied the CCD camera through a process called “dark subtraction.” It has also been determined that the most efficient temperature to take exposures at is approximately –25° centigrade (since the intrinsic noise is temperature dependent). This was determined by plotting the average pixel value of ten second dark frames against the temperature, ranging from –40° centigrade to room temperature, of the respective dark frames as illustrated in Figure 2. As shown there, reducing the temperature to below –25° centigrade reduced the efficiency of the camera since it takes a great deal more energy to only decrease the noise marginally after that point.
The software mentioned previously interprets the input data from the camera and has a utility that allows a star to be assigned a unit magnitude and every other star in that same image can be compared to that magnitude. The numerical values from these comparative magnitudes are displayed through this utility and a light curve will be developed from these magnitudes.

The observing techniques will first be tested by plotting a light curve for a short period variable star, possibly a member of the Dwarf Cepheids or the Beta Canis Majoris stars. Members of these groups have characteristic periods of between two to five hours, respectively, on average. Once the technique has been refined, a longer period variable star, perhaps a population I or population II Cepheid which have characteristic periods of between 5-10 days and 12-28 days, respectively, will be observed. As of this point in time, I plan to begin my prototype curve with β Canis Majoris which has a characteristic period of 5 approximately hours.

Once the data has been gathered, a Fourier analysis will be carried out in order to detect any periodicities that are not obvious from the star’s light curve. Further analysis of the Fourier analysis will lead to a formulation of a hypothesis as to what is causing the variation in the luminosity of the variable star observed.

Resources

The primary piece of apparatus will be a CCD (charged-coupled device) camera (specifically a model ST-6 CCD imaging camera manufactured by the Santa Barbara Instrument Group). Along with the CCD camera, a telescope around 6 inches in diameter
and between 50 to 100 inches in focal length will be needed, a laptop computer to receive the data input from the CCD camera, and Fourier analysis software. The budget is therefore minimal since all of the equipment is already possessed by Frostburg State University and can be provided.
Figure 2
Temperature vs. Average Pixel Value for a 10 Second Dark Exposure
Figure Captions:

Figure 1: This is a CCD image of the horse-head nebula which is very difficult to resolve with moderate sized telescopes. This image was taken by the manufactures of the camera and is a 900 second exposure.

Figure 2: This average pixel value for a 10 second dark frame vs. temperature plot shows how lowering the temperature below –25º centigrade reduces the efficiency of the camera since it takes a great deal more energy to only to decrease the noise marginally.

Works Cited


4. Reference 2, pp. 310-311.
APPENDIX C

Jupiter and three of four Galilean moons
November 24, 1998 at 22:14 EST
0.01 second exposure; f 78.8 in; aperture 7.79 in²; temperature –25.07° C; background 109; range 200
file name 24NOV078.ST6 (darks subtracted with DARK0P01.ST6)

Blooming effects, moon in upper left is Ganymede and in lower right is Io. Behind Ganymede is Europa.