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# CCD PHOTOMETRY AT THE UMR OBSERVATORY

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## ABSTRACT

During the summer of 1993 a number of advances at the University of Missouri-Rolla's observatory have taken place. These advances range from cleaning the mirrors and polar aligning the 16-inch Cassegrain telescope to the acquisition of needed supporting material. A program for observing variable stars, implementing the newly acquired CCDIR image reduction program, searching galaxies for supernova, and the possibility of adding low resolution stellar spectroscopy to our research capabilities will be discussed. This manual will discuss how to implement the new CCDIR program.

## INTRODUCTION

The summer of 1993 proved to be a challenging time in which to make astronomical observations. The lack of clear evenings hampered our attempts to make long term studies of celestial objects. However, we were able to make several repairs to our existing facilities and also acquire improved supporting materials.

The completed repairs include the cleaning of the mirrors of the telescope and the just completed polar alignment. The new supporting materials include the purchase of a Celestron C-80 telescope, the construction of a new carrying case for the CCD camera, the purchase of several variable star charts from the AAVSO, and the purchase of the CCD image reduction program CCDIR. These repairs and acquisitions will aid in the progress of future research projects.

For future research projects the new star charts and CCDIR program will be indispensable. The repairs to the telescope have been seen to have lowered our detection limit by almost two magnitudes. We have also

considered the possibility of providing the apparatus necessary to conduct low resolution stellar spectroscopy.

## **I. SUMMER OBSERVING SETBACKS**

With the summer of 1993 came the rains of 1993 ushering in the wettest summer on record. These rains made observing almost impossible due to the lack of clear nights. The beginning of the summer was to be used for myself to become quite familiar with how the telescope and CCD camera operated together. Unfortunately, this process took substantially longer due to the lack of clear nights.

However, in spite of the overcast conditions we were able to carry out several repairs (§ II.) which have improved the quality of our observational data.

## **II. ADVANCES**

The first repair conducted was the cleaning of the primary and secondary mirrors of the 16-inch telescope. With the aid of Dr. John Schmitt and David A. Thilker, the mirrors were painstakingly washed with cotton balls soaked in acetone. It should be noted that this procedure should NOT be done without Dr. Schmitt present. After initially cleaning the mirrors with acetone they were then rinsed with water to remove any further dust that was not removed with the cotton balls. This procedure has decreased the amount of scattering in the collected light. This has resulted in better image quality and has also lowered our detectable limit of stars down to approximately 17th magnitude, an almost two magnitude improvement.

The most recent repair, completed on 29 July 1993, was the polar alignment of the telescope. The procedure followed was that given by Sidgwick<sup>1</sup>. The motivation for this polar alignment was two fold. First, the realignment of the telescope has helped to minimize the tracking error caused by the aging electronics and stepper motors in the tracking system. Second, the declination and hour angle circles have been reset to roughly the correct positions. Having reset these, one can now find the declination and hour angle of an object and then simply adjust the telescope to these coordinates. We have found that the object of interest now usually appears in the field of view of the C-80 finder scope. Prior to this alignment, the declination was off by about two degrees and the hour angle off by several minutes. These discrepancies made locating any object extremely difficult. It would at times take

up to an hour to locate a single object. Now, though, the time required to locate an object has been decreased by about a factor of two.

The acquisition of the Celestron C-80 finder telescope has proved to be invaluable. This telescope has a field of view roughly five times that of the main telescope. With this larger field of view, locating the object of interest has become far easier.

Another problem in locating various objects, i.e., variable stars, has been the lack of adequate star maps. The computer programs that had been used in the past showed stars down to a magnitude of only 9.0. Unfortunately, we cannot limit the magnitude of stars seen to only 9th magnitude. This has made it somewhat difficult to locate some of the fainter objects. Also, many variable stars, at their brightest, are fainter than 9th magnitude. It is these stars that are of the most interest due to the lack of observational data collected from them. To this end we have ordered the Variable Star Atlas and about 125 individual variable star charts from the American Association of Variable Star Observers (AAVSO). The Variable Star Atlas shows stars down to 9th magnitude while the individual charts show stars down to around 11th magnitude. All of these charts will make the locating of the variable stars substantially easier. The programs we have been using do not give any indication of whether a star is a variable or not, so we had to rely on coordinates only obtained from various sources. As noted earlier, until the polar alignment locating an object on coordinates alone, with no star charts of the area, was impossible.

To be able to make serious variable star observations it is necessary to extract the stars magnitude from the CCD image. In order to avoid doing these calculations by hand, the CCDIR Astronomical CCD Image Reduction program was purchased. This program will accept image files in the FITS file format after being processed by conversion program accompanying the CCDIR program. A complete description of how to implement the program can be found in the observer's manual attached to the end of this report.

Two other measures were taken in order to enhance or observational facilities. The first was the construction of a carrying case for the CCD camera. Until recently, the CCD camera was moved to and from the observatory via a cardboard box filled with styrofoam "peanuts." We realized that in time this method of transportation could result in the damage of the camera. With a carrying case donated to us from the Cloud and Aerosol Sciences Laboratory and packing foam from a laser shipping case we have constructed a safe storage case

for the camera and its accessories. This case greatly increases the safety and ease of transporting the CCD to and from the observatory.

Secondly, Dr. Ron Bienik is currently writing a proposal to the National Science Foundation (NSF) for equipmental upgrades to our observatory. Dr. Bienik asked for Mr. Thilker's and my assistance in determining our future equipment needs.

### **III. FUTURE RESEARCH PROJECTS**

For future variable star research, I have included a complete and thorough explanation which can be found in the observational manual attached to the end of this report. The variable star charts described in § II. should be used for locating the stars of interest. Once the observational data has been reduced it can then be forwarded to the AAVSO to be combined with other observers across the nation to obtain an overall record of the star.

Work is currently under way to try and add low resolution stellar spectroscopy to our research capabilities. The apparatus is a modification of that used by Smith, Jefferson, and Tavenner<sup>2</sup>. The addition of this research will serve two purposes. First, it will allow an observer just beginning their career to become acquainted with the method of spectral classification of stars and also an analysis of stellar spectra. Second, there are several variable stars which do not exhibit a variability in magnitudes, rather in several of the spectral lines. Thus, having the necessary equipment to produce and examine stellar spectra, we would be able to also include these stars in a variable star research program.

### **IV. CONCLUSIONS**

Even with the persistent rains of the summer of 1993, a great deal of progress was made in our efforts to update and expand our observational astronomy facilities. The two major repairs, described above, have improved the quality of future images. The acquisition of the various AAVSO star maps will greatly increase the number of faint objects to be included in future studies and will also aid in the task of locating these objects. The purchase of the CCDIR program will aid in the reduction of images gathered. Finally, the observer's manual will provide a complete guide to collection and reduction of data gathered by future researchers.

## V. ACKNOWLEDGEMENTS

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1. J.B. Sidgwick, *Amateur Astronomer's Handbook* (Dover, New York, 1971) ch. 16.
2. C.P. Smith, S.N. Jefferson, E.L. Tavenner, *Ca II K Variability of the Solar Chromosphere*, Physics 332 Report (unpublished)

# **OBSERVER'S MANUAL**

**University of Missouri-Rolla Observatory**

**August 1993**

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## Introduction

This manual provides the reader with a complete description of variable star observations from arrival at the observatory to performing the data reduction and analysis. It is assumed that the reader knows how to properly operate the 16-inch Cassegrain telescope at the observatory and also has an understanding of sidereal time, declination, right ascension, and the hour angle.<sup>1,2</sup> However, for the inexperienced Charged-Coupled Device (CCD) camera user, detailed discussions are given concerning the proper operation of the CCD camera.<sup>3</sup> Should any problems with any of the equipment in the observatory arise Dr. Schmitt or the chairman of the Physics Department should be contacted as soon as possible. Enjoy your observations!

## Observing Session<sup>4</sup>

This chapter will guide you through an observing session from the time you arrive at the observatory until the time that you leave. It should be noted that the following procedures will vary in order depending upon the time of your observing session. It is advisable that you read through this entire section before proceeding to the observatory so that you may determine what order certain procedures need to be performed.

### 2.1 Setting up

After arriving at the observatory, the first thing you need to do is remove as much of the light pollution surrounding the observatory as possible. This is accomplished by turning off the light directly outside the observatory with the covered switch and then calling the UMR Police (ext 4300) and have the lights on the Engineering Research Laboratory (ERL) building turned off. Just tell the police your name, that you are at the observatory, and that you would like to have the lights on ERL turned off. This should be done as soon as you arrive since it may take the police up to an hour at times to have the lights turned off. You will need to plug in the tracking drive on the telescope, the motor for rotating the dome, and the motor for raising and lowering the slit since these should have been unplugged by the last observer. You will then need to remove all of the various covers on the telescopes. These should be placed such that the amount of dust, dirt, and other foreign particles settling on the portions facing the lenses or mirrors is a minimum. This will help in preventing dust build-ups on the various lenses and mirrors.

Now you can attach the CCD interface to the 16-inch telescope. This is accomplished by first removing the eyepiece holder by unscrewing it from the telescope. Be sure to place this in a safe location so as to avoid damage to it. Next, you can find the mounting screws and requisite allen wrench in the desk drawer. Position the interface such that its eyepiece points toward the smaller (white) finder scope and insert the mounting screws. Care should be exercised when attaching the interface to avoid damage to the interface, CCD camera, main telescope, or finder telescope. Once this is accomplished you may turn on the camera and begin the process of focusing it.

### 2.2 Turning on and focusing the CCD camera

Before applying power to the camera it is necessary to make sure that all of the connections are secure. Extra care should be exercised in making sure that the cable connecting

the CCD camera head and interpreter is secure. **DO NOT CONNECT OR DISCONNECT THIS CABLE FROM THE CAMERA OR INTERPRETER WHILE THE SYSTEM IS TURNED ON, TO DO SO WOULD SEVERELY DAMAGE THE CCD CAMERA HEAD!!**

Once the camera has been turned on you will need to enter into the ST6OPS program by typing ST6OPS at the command line of the directory with the program. You will see an information box appear telling you that the program is establishing a connection with the camera. If the program says that it cannot find the camera make sure that the program is checking the correct COM port. This can be checked or changed by going into the MISC menu and selecting the PC SETUP option. If the COM port is set correctly go to the CAMERA menu and select the ESTABLISH COM LINK... option. If it still will not recognize the camera you will need to refer to the CCD Operating Manual (there should be a copy in the observatory or in the SPS room in the Physics building).

Now, once ST6OPS has found the camera you will need to cool the camera down. This is done by selecting the SETUP option under the CAMERA menu. If the TEMPERATURE REGULATION is OFF set it to ACTIVE. Next, reset the SETPOINT, a good starting value is -20.00. In the lower right corner of the screen you will see a temperature value and a percentage in parentheses. The SETPOINT should be adjusted so that the percentage reads about 90%, this is the optimal operating temperature of the camera. The small white fan, which should be in the green cabinet somewhere, should be used to aid the cooling of the camera (this can be omitted during the winter months). Now that you have cooled the camera down you can now begin to focus the camera.

1. Adjust the focus ring on the interface such that it lies in the center of its travel range.
2. There should be three small metal bars used to find a good beginning point in focusing the camera. If you are using the camera on the main telescope find the ones marked "INTERFACE" and "SECONDARY MIRROR". The one marked INTERFACE should be placed such that one end lies on the mounting plate of the interface and the other touches the rectangular section of the interface. Adjust the focus ring so that this bar will fit in between the plate and interface. The one marked SECONDARY MIRROR should be placed so that it lies along the metal shaft of the adjustment knob. Adjust the mirror so that this bar lies completely along this metal shaft.
3. Using the finder scope, center a moderately faint star (magnitude 8) in the center of the field of view. You will also need to be sure that the tracking system has been turned on. If you do not hear the tracking system flip the switch to the ON position on the telescope. If you still hear nothing flip the switch on the hand paddle.
4. Now, under the CAMERA menu select the FOCUS mode for a series of 2 or 3 second integrations.

5. If no object appears in the image you may need to adjust the position of the star you have chosen.
6. As you watch the images appear on the computer screen, take note of the "peak" value. This number represents the highest pixel value recorded in the field of view. You will want to maximize this number, concentrating as many photons as possible into a small area.
7. In order to increase the peak value, slowly turn the focus ring slightly as the camera downloads an image. The next image downloaded, 2nd to be displayed, will reflect your adjustment. When the peak value of the image is maximized, allowing for fluctuations due to atmospheric instability, you have successfully focused the camera.

*Note:* If the first image of the star appears in the form of a "doughnut with spokes," the camera has not been adequately focused using the measuring bars. Return to step 2 and proceed once again.

Now that you have successfully focused the camera you can now adjust the tracking of the telescope so as to minimize tracking error.

### **2.3 Adjusting the tracking system**

In this section the method of evaluating and adjusting the telescope tracking system will be described. This will have to be done at every observing session since the tracking system response varies with outdoor conditions.

1. Select the full-frame FOCUS mode under the CAMERA menu.
2. Choose a moderately bright star lying near the center of the field of view.
3. If this star appears to drift over time some drive speed adjustments need to be made.
4. In this case, select the PLANET mode from among the FOCUS readout methods.
5. Isolate the direction of needed correction by grossly turning the rate potentiometer (located in the upper-right-hand corner of the paddle) in one direction or the other. *Only* take this action after noting the previous setting of the potentiometer dial.
6. By turning the pot in this manner you should be able to tell whether the original setting of the clock drive needed to be increased or decreased.
7. Return the pot to its original position and adjust accordingly.

8. Use the method of successive approximations in order to make the stars remain fixed. You should plan to watch the star for at least five frames to insure that the response of the drive is sufficient to hold a star in a fixed position.

Now that you have focused the camera and adjusted the tracking you can now begin to locate the objects which you wish to observe.

#### 2.4 Locating the object of interest

1. *Acquire a good star map.* Remember just how sensitive the CCD camera is. An exposure of a few seconds can record stars in the range of 16th magnitude. Most star maps or programs only show stars down to 7th, 8th, or 9th magnitude. The AAVSO variable star finder charts go down to 11th.
2. A good starting place is the telescope's setting circles and the finder scopes.
3. First, identify the right ascension (RA) and declination (DEC) associated with the star, galaxy, nebulae, cluster, or whatever tickles your fancy. This information can be found with most maps, in the current issue of the *Astronomical Almanac*, or even with a program like *The\_Sky for Windows*.
4. Next, compute the required hour angle using the INFOLOG astronomical Windows applications. Or for the more adventuresome,  $HA = RA - LMST^1$ .
5. Dial up the correct hour angle and declination on the telescope setting circles. A positive hour angle indicates pointing the telescope east, negative hour angles indicate a western direction. With the polar alignment in July 1993, the setting circles are fairly accurate and will get you very close to the desired object.
6. Look for the object in the finder scope. If you find it proceed to center the telescope on the appropriate field of view.
7. If you can't immediately locate the object visually in the finder scope, don't despair. The white finder presents a field of view on the order of more than one degree. This angular width corresponds to over ten CCD frames in each direction.
8. Now is where your star map becomes your most important tool. Identify the current field of view in the finder scope. Recall, the finder presents an inverted image with respect to the star map, north is south and east is west.

9. Based on your knowledge from the map, begin to devise a plan for "starhopping" from star to star to your object of interest. Use the telescope paddle to move the image in the finder. If there are two observers and you feel daring, unlock one telescope axis at a time as you starhop along. When starhopping in either manner, always keep in mind the relative distances between your "landmark" star. In this way, you may easily estimate the necessary magnitude of each successive movement.
10. It is not always humanly possible to see the object of interest in the finder scope. Usually, however, you can spot enough stars (found on your star chart) to "guess" where an object will be found.
11. Throughout the process of starhopping, it is always necessary to place the CCD camera in FOCUS mode using a reasonably long exposure time (5 or 10 seconds). You never know when you'll get lucky and chance upon the object of interest.

Now that you have set everything up, focused the camera, and have found the object you want to observe you can now begin to take data. First, though, a few things need to be said about flat fields, dark frames, and bias frames so that your data set will be complete.

## 2.5 Dark frames, flat fields, and bias frames

In order to extract meaningful data from the images you record you will need to do some radiometric corrections to the images. This will actually be discussed in some detail in § 3.1. For now, we will discuss the different images needed for this process.

First, we'll start with *light images*. Light images are those images which contain astronomical data. These images are reduced, or analyzed, by means of radiometric correction. These are the images that you will spend the majority of your time collecting.

Next, we come to the *dark frames*. Dark frames are used to remove the thermal background from a light image. The entire dark frame is subtracted from the light image being corrected before application of flat-field correction techniques. Dark frames must be of equal duration with respect to the light image, except with the shutter closed. Equal CCD temperature is also a necessary criterion. Fortunately, the ST6OPS program will automatically take and subtract a dark frame from an exposure. To insure this occurs, when you select the GRAB command under the CAMERA menu make sure that the DARK FRAME option is listed as also. ST6OPS will then take a dark frame of equal duration as the image automatically before taking a light image. As the image is downloaded from the camera the dark frame will be subtracted. Proceeding in this manner reduces the risk of using an inappropriate dark frame. Since the dark frame is taken just prior to the light image the temperature of the camera does not change a great deal between the two frames. Should you find that ST6OPS was not set to automatically take and subtract the dark frame, don't worry, just take a dark frame, by setting the DARK FRAME option to ONLY, as soon after the light image as possible. You can then instruct ST6OPS to subtract the dark frame later.

Now on to *flat-fields*. Flat-fields are used to correct for the systematic response variation

of each pixel on the CCD array. These images, which should be close to the exposure times of the light images, must be recorded while the camera is in focus and viewing a source of uniform illumination. There **MUST** be a flat-field for every filter that you have either used or plan to use. The two sources of uniform illumination available at the observatory are the twilight sky and also the dome being illuminated by the interior light. A flat-field image is recorded in the same manner as a normal light image. Point the telescope at the darkened (deep blue) twilight sky or the dome. Select the GRAB command under the CAMERA menu. Select the exposure time and set the DARK FRAME option to ALSO. Then proceed to take the image. In the case of using the dome it is necessary to have the dome rotating during the light exposure. By rotating the dome the image of the dome is averaged to remove the obvious non-uniformity of the dome. Once the image has been downloaded it can then be saved for use during radiometric correction.

Finally, we come to *bias frames*. Bias frames represent what the CCD camera would record if it looked at nothing for no time. These images record the systematic error introduced by the reset of the analog to digital converter. To record a bias frame, select the GRAB command under the CAMERA menu, set the exposure time to 10 milliseconds, and set DARK FRAME to ONLY. These images are used in the radiometric correction process which will be described in § 3.1.

## 2.6 Gathering Data

Now that we have discussed the necessary preliminaries, we can now turn our attention to the gathering of data. There are three different types of observing sessions, those from dusk into the night, those from the night into daybreak, and those only during the night. The only affect that the different times of observing have on the data gathering sequence is when and how to obtain your flat fields. The following method will be that of observing from dusk into the night, however, at the end of the procedure the changes for the other two observing sessions will be outlined.

1. You should plan to arrive at the observatory about 30 minutes prior to sunset. Once there proceed with § 2.1 Setting up, § 2.2 Turning on and focusing the CCD camera, and § 2.3 Adjusting the tracking system. Since stars may not yet be visible, you can focus the camera on the most distant earthly object you can find.
2. Now, as the sun sets record a suitable bias frame, as discussed earlier.
3. Now point the telescope at a relatively dark (deep blue) portion of the sky.
4. Proceed to record a flat-field, as described earlier, for each of the five filters (BVRI and the clear plate of glass). Be certain which position the filter wheel is in so that you can incorporate it into the file name. File names such as B\_FLAT.ST6, V\_FLAT.ST6, etc. are often most effective.

5. After the sky is dark and the stars have finally emerged you should re-focus the camera on a moderately faint star. Also be sure that the tracking has been set correctly to avoid tracking errors.
6. Next, proceed to locate your image using the method described above.
7. Once you have located the image you are now ready to take data. REMEMBER to always obtain an appropriate dark frame for each image.
8. When you are done for the evening make sure to shut everything down, see § 2.7.

If you are observing from the night into dawn the major change is when flat-fields are obtained. Once at the observatory you can set up, focus the camera, adjust the tracking system, and then proceed with step 6 of the above procedure. The flat-fields are obtained in the same manner with the exception that they are taken during the early morning twilight.

If you are only observing during the night then the flat-fields may be taken at any time during the session. In this case the flat-fields are actually called *dome-flats*. The procedure is the same except that the interior of the dome while being lit with the light inside the observatory is used as the source rather than the twilight sky. Remember to have the dome rotating during the light exposure so as to spatially average the interior of the dome. It is still necessary to obtain a unique flat-field for each filter.

## 2.7 Shutting down

Now that your observing session is complete the only thing left to do is to shut down the observatory. This is almost as important as taking data in that it will help insure that none of the equipment will be damaged until your or someone else's next observing session.

The first thing is to warm the camera back up. Go into the SETUP command under CAMERA and change the SETPOINT to about +10.00. While the camera is warming up you can disconnect it from the telescope and reattach the objective holder. Make sure that you unplug the tracking system. If the tracking system is left running the telescope will eventually crash into the cement pier and seriously damage it. ALWAYS place the dust covers over the mirror and lenses of the various telescopes. Before putting them back on make sure that no rocks, pieces of wood, or anything else has fallen into the portions facing the mirror and lenses. Once the covers are in place you will need to reset the telescope so that it points due north. The large ballast needs to point toward the floor and the main mirror of the telescope should point toward the north star. Once the camera has warmed up you can exit the ST6OPS program and replace the camera to the carrying case. Make sure to unplug the dome and slit motors from the wall sockets. Now before you lock up and leave for the night you will need to call the UMR Police back (4300) and tell them that they can turn the lights back on at the ERL Building. You MUST call and tell them this otherwise the lights will not get turned back on. Finally, just before you get into your car, or whatever you came in, turn the light on just outside the observatory. Now that you have gathered your data and returned home you can now begin to analyze your data.



## Data Reduction

This chapter will discuss the method of radiometric correction and the use of the CCDIR programs. The method of performing differential photometry by hand has been discussed in detail elsewhere<sup>5</sup> and will not be discussed here. Due to the large number of commands used by the CCDRED and CCDPHOT programs, rather than rewrite the Reference Manuals<sup>6</sup>, only a brief description of their purposes will be given

### 3.1 Radiometric Correction

The process of radiometric correction to the CCD images is necessary before using CCDIR or doing differential photometry the old fashioned way. Without these corrections, any calculations would be in error.

The first step is to load the desired image and subtract a dark frame from it. As discussed earlier, this is most easily accomplished by letting ST6OPS take and subtract a dark frame from each image as it is downloaded. If this has not been done, then you will need to enter the UTILITY menu and select the SUBTRACT DARK FRAME option. ST6OPS will ask for the dark frame file name. Remember, the exposure time and camera temperature of the dark image must be the same as the light image being corrected.

Next, the bias frame can be subtracted from the image using the same technique as for subtracting a dark frame. This removes the error introduced by the resetting of the A/D converter.

Now, also under the UTILITY menu, choose the FLAT-FIELD option in order to divide the current image by an appropriate flat-field. The filter type MUST match. If the flat-field is not of the same filter the resulting image will be useless.

To remove the effects of any cosmic ray events or dead pixels select the REMOVE HOT PIXELS and the REMOVE COOL PIXELS commands. Once all of these corrections have been completed you can now proceed to reduce the image using the CCDIR program.

### 3.2 CCDIR and supporting programs

#### 3.2.1 FITS File conversion

In order to use the CCDIR program the file format from ST6OPS must be modified to conform to the appropriate FITS file format. The image should be saved in the FITS file format. Next, you will need to run the FITS File Conversion program. For this you will need

to record the header information manually at the telescope. You will then need to create a header file using an ASCII editor (the MS-DOS editor will do just fine). The header should follow the format given below in Table I.

**Table I Header File Format<sup>6</sup>**

ITEM	COLUMNS	COMMENTS
File name	1 - 30	File name of the image, may include a path
Object ID	33 - 62	Object name etc.
UT hour	65 - 66	UT hour at START of exposure
UT minute	68 - 69	UT minute at START of exposure
UT seconds	71 - 72	UT seconds at START of exposure
Year	75 - 78	4 digit year (e.g. 1993)
UT month	80 - 81	2 digit month (e.g. August = 08)
UT day	83 - 84	2 digit day
Image type	87 - 92	image type (object, bias, flat, dark)
Exposure	95 - 98	exposure in seconds
Filter ID	101 - 106	Filter designation
Right Ascension	109 - 116	Right ascension in format: HH.MMSS
Declination	119 - 126	Declination in format: HH.MMSS
Epoch	129 - 136	Epoch of coordinates (e.g. 1993.5)
Comment	139 - 202	comment field

To execute the program type FITS at the prompt while in the directory where the program is located. The program will prompt you for all other necessary information.

### 3.2.2 CCDRED and CCDPHOT

CCDRED performs the same radiometric correction operations as ST6OPS does. It will subtract out the dark frame and bias frame and will also divide the image by the appropriate flat-field. However, CCDRED does perform one very important operation that ST6OPS will not, it will extract from the image the instrumental magnitudes of selected objects. For any given image 30 instrumental magnitudes may be extracted. These magnitudes are written to a file which is then passed on to the CCDPHOT program for further manipulation.

CCDPHOT accepts data files created by the EXTRACT command of CCDRED and reduce the data for either differential or all-sky photometry. The DIFF command is used for processing differential photometry. This is similar to the process described by Hall.<sup>5</sup> The EXT1 command is used to calculate the atmospheric extinction coefficients from observations of a single star over a range of air mass. In order to perform this you will need to have multiple observations of the star during the same evening. The EXT2 command determines the atmospheric extinction coefficients from observations of stars whose first color index (i.e. the color index which uses the magnitude filter) is near zero. For the UBV system, this color index would be B - V, because V is the magnitude filter. The EXT3 command determines the atmospheric extinction coefficients from observations of standard stars (of any color) at various air masses, *when the transformation coefficients are known*. These coefficients are obtained by executing the TRAN command. The TRAN command determines the coefficients to the standard photometric system. Finally, the CONV command converts the instrumental magnitudes into standardized magnitudes and colors and writes the information to a file.

From these brief descriptions of what these programs can do, it is easy to see just how valuable they are to anyone doing CCD photometry research. All of the programs described here can be found in the PHYS 11 accounts on the Department of Physics file server. Should you have any problems with these programs you should first consult the reference manuals and if you are still having problems you should then contact Dr. Schmitt.

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