CCD Photometry
Part One: Introduction and Image Calibration

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A Short Course in the AAVSO CHOICE Program

Course Introduction

This course is the first in a two-part online course in CCD Photometry. In the past, the AAVSO has provided resources intended to help you become better "CCD Observers". For the purpose of this course, we want to help you become better CCD Photometrists. There is a subtle difference there, which we hope to make clear as time goes on. Primarily, we want to teach you how to take, calibrate, measure, and analyze image data from your CCD camera so that your time and effort provide users of your data maximum scientific benefit while at the same time helping you achieve maximum satisfaction from your observing session. Science is important, but so is your enjoyment of astronomy.

The quality of equipment has increased as dramatically as the cost of that equipment has fallen, but in most respects the fundamental design and use of CCD technology is identical to what it was twenty years ago. We'll also be drawing heavily on other AAVSO resources, including the CCD Photometry course given in 2012 by AAVSO Director Arne Henden, as well as the book on CCD Photometry in preparation by Arne. This course is being taught from the *AAVSO Guide to CCD Photometry*. Your feedback during this course will be greatly appreciated, and will help us to make improvements in order for us to better serve the community's needs. We're happy to take both compliments and constructive criticism, and we want to help you understand things where you find them unclear.

What we can't do is provide tech support for your image processing and analysis software. You are expected to be familiar with basic operations of your software and will need to learn the commands for doing common operations like combining images (stacking, addition, subtraction, and division) or obtaining statistical information about the images. There are too many different vendors (and too little time) for us to be of much help here. That said, if you have questions about how your software does something, post them to our forum and we or another student will see if we can find the answer quickly. Please help each other out when you can! Since this is an online course, communication will mostly be via the AAVSO Forum and by private email when you feel the need.

The AAVSO Choice Program courses are taught by volunteers. Your volunteer instructor is knowledgeable but not omnipotent and will not hesitate to query Headquarters if the question warrants. You should feel free to ask questions and bring up topics that are relevant to the course and not be limited by the discussion questions in the course syllabus. If we get off topic, your instructor will give notice.

Important: Participation in discussions is a required part of the course. Even if you think you have no more to add to the discussion on a topic, you can always state how one or another student's responses squares with your experience. But don't just say you agree with Student X, say why you agree.

Assumptions: You should have access to (1) a scope with a CCD camera, (2) processing software. Valuable and needed for CCD2: at least one photometric filter (Johnson V recommended, B valuable and needed in CCD2. If you do not have a CCD camera it is still possible to participate in the course by using images in the Dropbox.

Warning: This is a CCD course, not a DSLR or CMOS course. This course does not cover the way to process DSLR images for photometry and I have no experience with CMOS cameras vis-à-vis photometry. Use the images in the Dropbox.

Assignment through the course: Do not hesitate to read ahead, fire up your camera and take calibration frames as well as "lights" of variable star fields. Work with your software. Much of what we discuss will be greatly enhanced if you already have these images on your computer because we will be delving into the *nature* of calibration and light frames, not simply how to take them. The "taking" ranges from trivial (bias frames) to hard (flat frames). The "understanding" is another matter and what this course is about. You may not know things like your linearity when you start. No matter, you will, we hope, by the end of the course. So, shoot away, its only photons and electrons.

Course Syllabus

Week One: Introductions, Goals and Equipment

- Student and instructor introductions
- What is photometry and what are the goals for good astrophysical photometry?
- Equipment overview
- Not kidding – begin to take your calibration frames – if needed read ahead to the quick guide InfoBox 4.1. I suspect most of you have some experience, if not, it's even more important that you begin using your equipment.
- **Reading**: CCD Photometry Guide, Chapters 1-2 plus first 2 pages of Chapter 3.

Week Two: Getting to know your camera

- The CCD Chip

- How linear is your camera?
- Sampling, FOV and other characteristics.
- Filters, software and charts
- **Reading**: CCD Photometry Guide, Chapter 3
- **Reading**: In addition, you should have figured out how to use your software when performing the linear test, continue to review the software manual and tutorials.

Week Three: Unwanted Signal

- **If you have not taken calibration frames, you need to do so.**
- Bias and Dark frames: what are they and what do they measure
- Generating bias frames • Creating a Master Bias
- Generating dark frames and Master Darks
- Flat fields, what they are and how to create them.
- **Reading**: CCD Photometry Guide, Chapter 4 (biases, darks, flats)

Week Four: Putting it all together

- Calibration: separating the signal you want from the signal you do not want
- Characteristics of the calibrated light
- Introduction to VPhot
- Course wrap-up

Discussion Questions

Week 1: Principles and purpose of photometry

1. What is your understanding of the word "calibration" at the start of the course? What does it mean and why are we considering it here?

2. In the manual, we make the statement that we want data that accurately represents reality so that users of your data can make good physical models of what we see. What does "accurate" mean? How accurate is "accurate"? Is there a difference between precision and accuracy? How might you as an observer assess how good is "good enough"?

3. Tell us about your equipment and interests. How is your equipment going to shape your observing program? How is it going to limit your program? Among the possible subjects you may wish to share are (1) the kind of telescope and its mounting, (2) your setup (do you set up each night or have a permanent setup), (3) camera and filters, (4) software. Have you submitted data to AAVSO or other organizations that house data on variable stars? Any class of variables you are interested in observing?

Week 2: Equipment and software basics

1. Is your camera NABG or ABG. What are your linearity limits? For example, My Atik4000 is an ABG camera and becomes non-linear around 45-50K ADU. Now measure the

2. What is the FOV and image scale of your system when you use Bin 1x1 sampling? How does this differ when you use Bin 2x2 sampling?

3. Given the characteristics of your observing site (consider your average FWHM), what binning would you use? Would the magnitude of your variable have any effect on your binning decision? How about filters?

4. Pick out a variable you might be interested in observing. Using your knowledge of your FOV, download a chart of the scale appropriate to your FOV, and the associated photometry of the comparison stars. Access the information available in the VSX. Send me the chart, photometry data and VSX information along with your thoughts on a program of observing for this star.

Week 3: Calibration frames

1. What's the typical pixel value for your bias frame and dark frame? (To find this sample a large part of one bias and one dark.) What is the difference between the average pixel values? What do you think accounts for the difference? When will these two effects (bias or dark signal) have a larger impact on photometry: bright star photometry or faint star photometry?

2. Discuss any structure that you see in your bias and dark frames, and if possible share the images with the class. To reveal the structure, try something like "pushing" the image with your software to bring out the details. See any white pixels in your darks? Amp glow?

3. There are two strategies for dark and bias calibration. Which do you plan to use in your observing program?

4. What is your strategy for taking flat field frames? Share a raw flat with us. Any vignetting? Lots of dust bunnies showing up? Any totally black regions?

5. If you have not done so, please prepare your master calibration frames. Share them with us and tell us how you made them. It is instructive to compare the ADU counts of masters and single frames.

Week 4: Putting it all together

1. Using your various calibration masters, calibrate some images using your software. Convert the uncalibrated image and the calibrated image to jpegs for easy uploading and share them with us. Again, "pushing" images to reveal details is good.

2. If you have multiple filters (or a color filter and a parfocal clear filter) compare the two frames. What are the same and what are different? If you see different features in different filters, what does that (probably) tell you about the physical location of what's causing the feature?

3. If you have chosen to try VPhot, were you successful in establishing an account and uploading calibrated images?

4. Take one of your calibrated images and the matching uncalibrated image. Do one of two things. (1) Sample across the both images with a line profile tool if your software has one (e.g. AIP4WIN). Or (2) sample ADU counts in some of the same “blank” regions of both images. (1) will give you a graphic view of the levels of noise differences. (2) will give you a quantitative measure of the resulting differences. Report what you see or measure (or both).

Final Exercises

Exercise 1: Use the AAVSO light curve generator (www.aavso.org/lcg) to look at TWO of the following light curves covering the past five years (1825 days): khi Cyg, omi Cet, R Sct, SS Cyg, GK Per, Z Cam, alf Ori, W Cas. (Choose any two you like.) Assess two things for each: how quickly the star appears to vary, and what the amplitude is. Estimate (a) how often you should observe, and (b) what accuracy level you'd need to provide useful data. Briefly discuss how you made that assessment.

Exercise 2: Do you have light leaks? Take dark frames with 1, 10, and 100 second exposure times. Discuss what you see. If you can slew the telescope and/or change the lighting within your observatory, do that. Retake your darks. Do you see any differences? [If the answer is yes, you need to track down why! It's probably a light leak.]

Exercise 3. See the difference between two master flats. Split your raw flats into two groups. Prepare new master flats for each group. So, if you made 10 raw flats for the V-filter, you would have two new masters made from five flats each (or ten if you made 20, etc.). Now divide one master flat from the other. What do you see? How do you think this might differ if you compared one flat to another taken a month apart? Do you think they might differ if taken at very different focus points?

Exercise 4. In your own words, describe the calibration process. What does each calibration frame do to the science image?