CCD Basics: Astronomical Imaging

I. What is a CCD?

Virtually all the astronomical images (any many other images) you see today are produced by CCD (which stands for charged coupled device) detectors or cameras. Only a few years ago this technology was only found in science labs, but today everyone has experience with digital cameras, as well as other forms of CCDs. The term “pixel”, standing for “picture element” is common: a CCD in a digital camera produces an “image” composed of megapixels (millions of pixels). In astronomy, CCD's replaced photography in the mid 1980's because of the tremendous advantages they offered. A photographic image can record about 5% of the light that reaches the film; modern CCDs can record up to 90% of the light. Photographs must be carefully developed in a darkroom, where the result can be very dependent on the temperature and strength of the chemical developers, and copies are always inferior to the original image. The digital image from a CCD is immediately stored electronically, and is completely reproducible. A CCD image is also what we refer to as linear: doubling the exposure time exactly doubles the intensity of the image – something that is only approximately true with photographic film. And while your digital camera unobtrusively produces color images that you can manipulate with software programs, astronomers appreciate the characteristics of CCD that make it possible to record an image through different filters and then analyze the separate images.

But what are those pixels? A CCD is sort of a reusable piece of film. (Although these days most people probably have no experience with film!) It is composed of picture elements, or pixels, in an array, or x-y plot. Typically a CCD has a few thousand pixels in what we term the x axis, and the same number in the y axis. (So the product of the number of pixels in the x axis by the number in the y axis equals the total number of pixels in the CCD So ask yourself: if a CCD is listed as having a total of 4.19 megapixles, what is its dimensions in pixels? – allow for roundoff error .)

When the camera takes an exposure, these pixels collect light that is converted to an electric charge when it hits the pixel surface. We describe light as either a wave or a particle: here we treat light as a particle called a photon. (Although photons of different color are described by different wavelength.) You can think of each pixel as a little bucket open to the rain of photons. At the conclusion of the exposure, the electric charge is read out in a sort of bucket brigade. (See an animation at astro.swarthmore.edu/astro121/readout.gif.) At the read-out point, the electrical charge in each pixel is converted to a number representing the number of light photons in that “bucket”. These numbers are saved in the computer and can be manipulated to produce the final image.

II. How Does a CCD produce color images?

In the previous discussion of the CCD you may have noticed that there was no discussion of the color of the image. The number associated with each pixel read out represents all the light photons that fall into the “bucket”: red photons , green photons, blue photons etc. So to make a color image, several additional steps involving filters are necessary. A filter is simply a piece of glass or film than permits only light of a specific wavelength range to pass through. (Think of a piece of colored cellophane.) Astronomers put a filter in front of the CCD and take an image. Then they take another image of the same object with a different filter, and then with a third filter. Three filtered images allows us to create a color image.

The pixels in the images are each assigned an appropriate color by the computer for that filter, with the degree of color depending on the amount of charge that was read out for the pixel. These different images are combined to produce the final image, as figure 1 below illustrates.

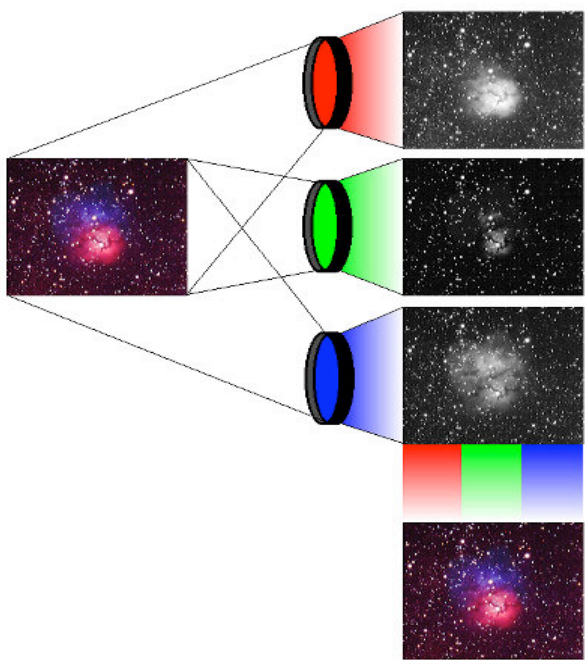

Fig. 1 Combining images to produce a color image