Section 2: Acquiring Images

Focusing for CCD imaging involves multiple steps. It's an iterative process that involves gradually refining focus until you've got the best possible focus. Many times, you will go back and forth through best focus so you can find out where it is. The trick is to then move back to that perfect focus position.

You can determine focus in a variety of ways, and we'll look at these methods in this chapter:

- Visual focusing (quick but not always the most reliable)

- Software-assisted focusing (not as quick, but can be very reliable with the right focuser)

- Hardware-assisted focusing (slowest, but very reliable)

Figure 2.2.1 shows some typical star images in and out of focus. The telescope used for the example on the left is a refractor. The well-out-of-focus image is a broad circle with faint diffraction rings visible between the center and the edge. (Out of focus is about the only time you will encounter diffraction rings in your imaging.)

The example on the right shows a focused image that is typical of a telescope with a secondary mirror supported by a spider, such as a Newtonian. The length and thickness of the diffraction spikes will vary from one telescope model to another. Other types of telescopes will have their own characteristic out-of-focus appearance. Schmidt-Cassegrains, for example, will show the shadow of the secondary mirror if you are far enough out of focus.

TIP: Focusing by eye is a challenge. Always choose a bright star to do your visual focusing. Exactly how bright a star to choose depends on many factors, including the focal ratio of your telescope, the sensitivity of your camera, the seeing conditions, etc. You want a bright star that will not saturate your camera. See chapter 6 for details on calculating the saturation level of your CCD camera.

Figure 2.2.2 shows a succession of star images, ranging from moderately out of focus at left to accurately focused on the right. Notice that dim stars are invisible when you are out of focus, and as you get to critical focus more and more dim stars appear in the image.
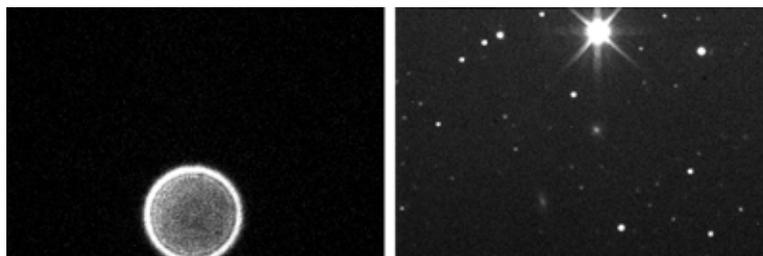

FIGURE 2.2.1. IN A REFRACTOR (LEFT), THE OUT-OF-FOCUS STAR IS CIRCULAR. IN MANY REFLECTORS (RIGHT), SPIDER VANES ADD DIFFRACTION SPIKES.

The simplest (but not necessarily the easiest) way to visually focus for CCD imaging is to observe a star image in your camera control software while making adjustments to the telescope's focuser. There are several attributes of a star image that you can use to determine when you are in focus, including the size of the star image and the nature of its border.

FIGURE 2.2.2. THE CHANGING APPEARANCE OF STARS AS FOCUS IMPROVES.

The size of the star image – As you get closer to the best focus point, the star image will shrink to a smaller size, as shown in figure 2.2.2. Although the star is a point source, you will not be able to shrink a bright star down to a very small point no matter how perfectly you focus the telescope. The brighter the star, the larger it will be in your image. The movement of air in the atmosphere spreads out the light from the star and causes the stars to twinkle (the technical term is scintillation). If the air is very steady, you will get smaller star images ; when the air is turbulent, you will get larger "bloated" star images. In later sections, you'll learn about Full Width at Half Maximum (FWHM), a tool that measures the width of the star image. FWHM isn't as complex as it sounds. If you were to plot the brightness of a star as a curve, the FWHM is the width of the curve at half brightness.

TIP: To judge focus accurately, first estimate how much the star's size is being affected by turbulence. If there is a wide range of focuser movement that shows no improvement in focus, then turbulence is making star images larger than normal. Focus will be difficult to optimize (longer focal lengths are more prone to this). Likewise, if very small amounts of focuser movement show changes in star size, seeing is more stable and you will have small, tight star images. Such conditions lend themselves to capturing excellent images.

The border of the star image – When a star is out of focus, there will appear to be a small cloud or halo around it that indicates poor focus. You may need to adjust the image contrast to see this border area. Figure 2.2.3 shows two highly magnified images of a very

bright star. Can you guess which star image is in focus, and which is not? It's easier doing it with real software, because the difference is very subtle. It takes time to develop an eye for the differences.

TIP: The method you use to adjust image contrast is similar in various camera control packages, but the names of the adjustments differ. These are just different names for the same things. For example, in CCDOPS and CCDSoft you adjust the settings for Back and Range; in Maxim/DL you adjust Minimum and Maximum. See chapter 8 for more information.

The left image in figure 2.2.3 is only a little bit out of focus. The edge of the star in the left image is just a little less distinct than in the right image. The trick here is that an out of focus star image does not have as hard an edge as an in-focus star image. If the star is too bright, it will be harder to see the difference. If the star is too dim, it will disappear entirely if you move outside of focus.

To see the visual difference between in focus and out of focus most clearly, zoom in on the star image to get a good look at the edges of the star. If they are soft, you are still outside of critical focus. If the edge of the star shows a sharper cut-off between the star and the background, you are very close to critical focus. This technique requires experience to do well, however. There is always some degree of fuzziness at the edge, and learning how much is just right takes trial and error. The difference between focused and not focused can be very subtle, and hard to distinguish for the unpracticed eye. That is why more sophisticated focusing techniques have been developed, such as Hartmann masks, diffraction focusing, using dim rather than bright stars for visual assessment, automated focusing, etc.

To complicate bright-star focusing further, two other conditions have symptoms that are similar to the out of focus star: turbulence and poor collimation. Turbulence in the atmosphere will scatter the star's light – the greater the turbulence, the greater the scatter. The results of turbulence are nearly identical to poor focus.

FIGURE 2.2.3. THE RIGHT IMAGE IS SLIGHTLY BETTER FOCUSED. IT SHOWS SUBTLE SIGNS OF A HARDER EDGE.
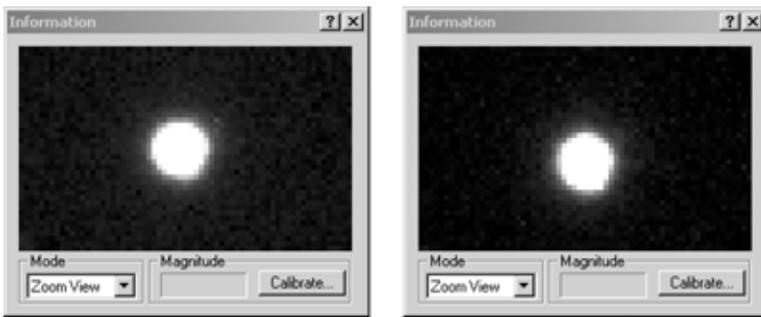
Poor collimation also scatters light, but in a characteristic fashion. In focus, poor collimation shows up as a stretching of the star image radially, with a gradual fading along the axis of the stretch (see figure 2.2.4). Slightly out of focus, the star image forms a ring with one side of the ring being brighter than the other. If the focus is too far out, you won't see this effect. When a scope that is poorly collimated is used for imaging, the image will never quite come to focus, no matter how hard you try. See chapter 3 for information about collimating telescopes.

TIP: The amount of zoom you use to examine focus quality determines the technique to use. If you use a zoom factor of 300-400% or 3-4X), you should look for an overall appearance of crispness at the edge of the star. If you enlarge the image further, up to about 800% or 8X, you will be able to see individual pixels – you can actually count the number of pixels that the star occupies. However, the FWHM measurement, discussed later, is a much easier way to determine the width of the star. Best focus is typically achieved when the number of pixels spanned by the star is at a minimum. If you are counting pixels, and the number of pixels spanned by the star changes even when you are not making changes to the focuser, then you are dealing with turbulence.

Telescopes vary dramatically in how well they preserve the contrast of an object. If a telescope has poor contrast, that will adversely affect image quality and make it harder to detect best focus. The better the
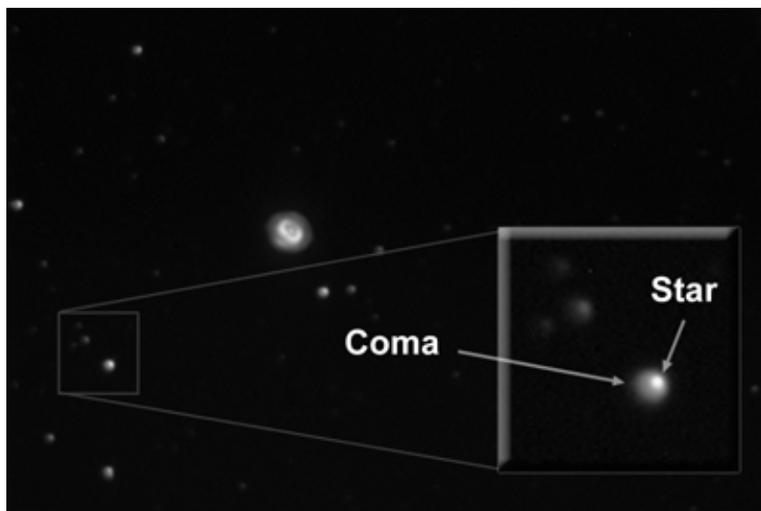

FIGURE 2.2.4. COMA LOOKS SOMEWHAT DIFFERENT THAN A POORLY FOCUSED STAR. THE BRIGHT CORE OF THE STAR IS OFFSET FROM THE CENTER.

optics are, the better the telescope's contrast will be. Another important factor is light scattering. Internal baffles can reduce reflections inside the telescope, and a dew shield can reduce the amount of off-axis light entering the telescope, which will help reduce internal reflections. Smooth, well-finished optics also reduce scattering.

The Focusing Process

The typical focusing process starts with invoking the focus routine in your camera control software. For SBIG's CCDOPS program, the focus dialog (see figure 2.2.5) presents you with four options:

Exposure Time – The length of time to expose the CCD chip. Bright stars require short exposure times, typically on the order of a fraction of a second. The dimmer the star, the longer your exposure time must be to get enough of an image to evaluate focus. Exposures over 2 seconds average out turbulence effects.

Frame size – This is a somewhat deceptive term. What you are changing here is the bin mode. The idea is to use a coarse bin mode (2x2, 3x3) for rough focusing, and unbinned mode (1x1) for fine focusing. In CCDOPS, the coarsest bin mode is called "Dim" because it is useful for locating dim objects using short exposures. Once you get a good rough focus, switch to Planet mode.

FIGURE 2.2.5. THE FOCUS DIALOG FROM SBIG'S CCDOPS CAMERA CONTROL SOFTWARE.
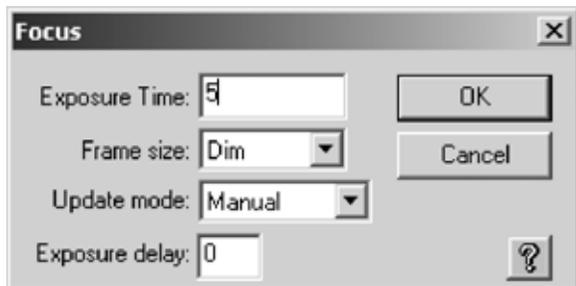
Update mode – Determines how the focus exposures occur: manually or automatically. Manual mode will take just one exposure, and then wait for you to click a button to take the next exposure. Automatic mode takes one exposure after another, with a delay between exposures if you enter a value into the Exposure Delay box. Once you gain experience with focusing, you can do most of your rough focusing in automatic mode. I prefer manual mode for final focusing because I like to study the image carefully to evaluate focus.

Exposure delay – How long to wait between exposures in automatic mode. Enter the number of seconds to delay. Once you are comfortable with focusing procedures, you can use the Automatic update mode, and set an exposure delay of around 3-10 seconds. During the delay, you can evaluate focus quality and adjust focus position.

Other camera control programs offer similar settings that allow you to manage the focusing process. Maxim/DL offers additional focusing options that are covered throughout this chapter. CCDSoft offers an excellent set of focus tools, as well as an automated focusing tool called @Focus which is covered in detail later in this chapter. Version 3 of MaxIm DL also includes automatic focusing tools. See the book web site for information.

Whatever software you use, the focusing routine is fairly standardized:

- Determine the appropriate exposure time by imaging a star field.
- Take an exposure (or initiate automatic exposures).
- Adjust the focus position, and take another exposure. Does it make the focus better or worse? This step determines the direction to move the focuser to improve focus.
- Repeatedly take exposures and adjust the focus position to improve focus.
- Continue until you have moved past the point of best focus, taking note of the appearance of the star at best focus.
- Move back to the point of best focus, and verify focus quality.

TIP: The only way to know if you really have reached best focus is to go past it and observe a decline in focus quality. Otherwise, there may be a better focus point than the one you currently have – you just won't know it! By continuing until the focus gets worse, you can make sure you reach the best focus position.

On some nights, the seeing will be poor, and there will be a zone where focus won't get any better. Stars will be larger than on other nights. Your best strategy is to position the focuser in the middle of that zone. On other nights, you will have a very small range of positions where focus is best, and you will get stars that are small dots of light. Those are the nights to stay up all night imaging!

Rough focusing should be done using the binning features of your CCD camera. Start with a full frame. Binning combines multiple pixels, and results in faster download times. (See chapter 1 for details on binning modes.) Binning results in less time to download the data from the camera because there are fewer pixels to download. If you bin 2x2, for example, you can download an entire frame in one-fourth the time, since each virtual pixel is now made up of four actual pixels.

1x1 binning – This is really no binning at all, but you will often see this phrase used anyway. It simply means that the camera has been used at its highest resolution: one pixel in the camera equals one pixel in the image. Final focusing should be done at 1x1 binning; higher levels of binning can mask focus errors. However, if you don't normally use 1x1 binning because your focal length is very long, then focusing at 1x1 will just give you a larger fuzzy star, and may not help. In that case, use whatever bin mode you use for imaging for focusing as well. See figure 2.2.6 for an example of a 1x1 binned image taken with an ST-8E camera.

2x2 binning – Pixels are binned in groups of four, two pixels on a side. If 2x2 binning is the largest available bin mode, you can use it for rough focusing. Figure 2.2.7 shows an example of 1x1 and 2x2 binned images with the 2x2 image (left) enlarged to match the 1x1 image (right). The 2x2 image has much less resolution. The area of the 2x2 image is just one-quarter of the 1x1 binned image (see figure 2.2.8). This is why imagers typically use the smallest bin mode on any given night, limited only by the seeing conditions and focal length.

FIGURE 2.2.6. AN IMAGE OF M15 UNBINNED (1X1).

3x3 binning – Not all cameras offer 3x3 binning. It's the fastest way to do rough focusing. With many telescopes, but especially SCTs (Schmidt-Cassegrains), you may start with a star image that is dramatically out of focus . Binning 3x3 lets you use the entire chip for rough focusing with fast download times.

Other special-purpose binning modes are sometimes available. They are used for special purposes such as spectroscopy, and can be ignored for focusing.

Larger bin modes are more sensitive for the shorter exposures used in focusing. You can also use larger bin modes to quickly see if the object of interest is within the field of view. This allows you to see what you are pointing at using shorter exposures than would be possible without binning. This works extremely well for bright objects like clusters, but it is also surprisingly effective with galaxies and nebulae. I am always amazed when I can clearly see dim objects in my focus images, even though they are only 5 to 10 seconds long.

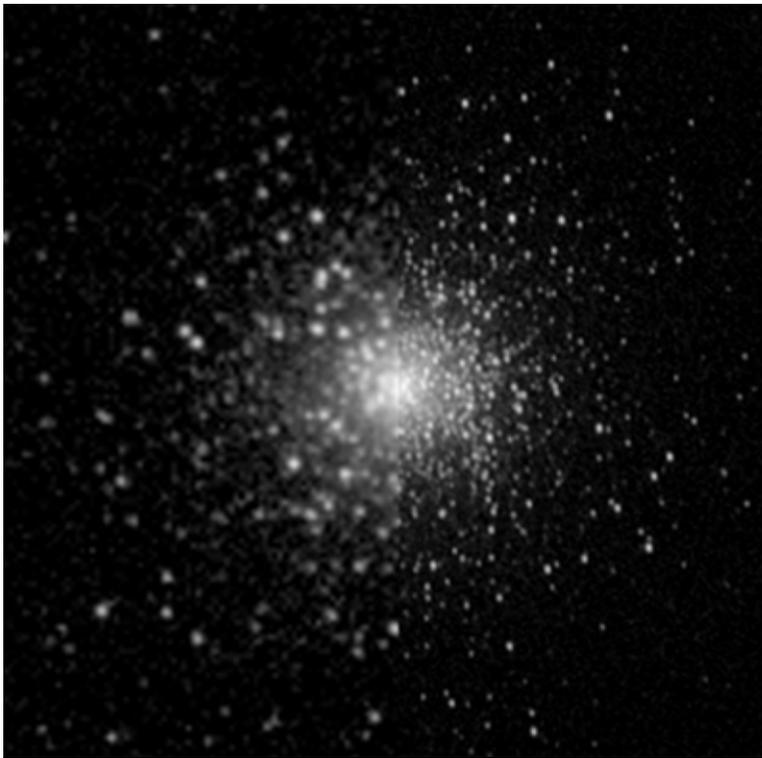FIGURE 2.2.7. COMPARISON OF 2X2 (LEFT) AND 1X1 (RIGHT) BIN MODES AT THE SAME SCALE.

FIGURE 2.2.8. A 2X2-BINNED IMAGE OF M15, SAME SCALE AS FIGURE 2.2.6.

Moving Primary Mirror Issues

Most Schmidt-Cassegrain telescopes, and many scopes of similar design such as Maksutov-Cassegrains, focus by moving their primary mirror. Most such systems do not support the mirror rigidly. The mirror will shift when slewing and tracking, and when reversing focus direction. The shifting will alter the focus position, and/or cause the field of view to move to a different part of the sky.

When the primary mirror is moved to adjust focus, it moves both along the telescope axis, as intended, and it also moves laterally and it may change its tilt. This can cause image shift and slight astigmatism. The problem is most noticeable when you change the direction of focus travel. The amount varies from one scope to the next, but it is often annoyingly large.

When changing focus direction, not only does the mirror shift laterally, but it may also alter the focus in large jumps. This makes it challenging to get accurate focus with a moving primary mirror, and accounts for the large market in add-on focusers. It takes some practice to get good at focusing with the moving primary. One approach is to go past best focus, then go back through focus, and approach focus from the original direction and be very careful not to go past it. Otherwise, if you try to return to focus by reversing direction, your object may be moved too much. You typically wind up repeating the focus procedure until you get to best focus without going past it. When the seeing is marginal, that adds to the frustration of this maneuver. That is why alternative focusers, covered later in this chapter, are often used on scopes with moving primary mirrors.

If you do mount an alternate focuser on a scope with a moving primary, you may want to lock the primary down. Several web sites offer different methods for locking the mirror, and the method you choose will depend on the make and model of your telescope. It is easiest on many Meade SCTs, because you can simply put the locking bolt that was used for shipping back into the scope. With other models, you will probably need to drill into the back of the scope and add your own locking bolt(s). This is a non-trivial procedure, but it can make the scope a much better one for CCD imaging. Make sure you put a soft tip of some kind on the lockdown bolt to prevent damaging the mirror, and never apply excessive pressure to any of the bolts.

The moving primary rides on a hollow tube. A layer of grease keeps the mirror from sliding around too much, but it does not keep the mirror perfectly still. When you move the telescope to point at a new object, the mirror may shift a little as the weighting changes. This makes it more challenging to use a finder scope, digital setting circles, or a goto mount with one of these scopes. The longer your focal length, the more of an issue this will be.

When you flip the telescope across the meridian (that is the line directly over head running from north to south), the mirror may shift by a larger amount because the weighting has changed by 180 degrees.

This is not to say you cannot use a telescope with a moving primary for CCD imaging. Many of the CCD images out there have been taken with such telescopes. The issue is important but not as nasty as it sounds. The end result of having a moving primary mirror is that a certain percentage of your shots will be ruined by mirror movement, but it's typically no more than 20% of the time. If you can't live with that (and your results could be better or worse than that average), you can lock down the mirror, and use an alternative focuser such as the JMI NGF-S.

The Zen of Focusing

It might seem from the discussion so far that focusing is too complex to deal with easily. In some ways, this is true. Focusing involves a lot of steps and varaiables, any one of which can get in your way on a given night of imaging.

On the other hand, focusing is the key to getting good CCD images. If you can master focusing, you have gone a long way toward your goal of obtaining great images.

Many first-time CCD imagers bring a set of assumptions to the job of focusing. A typical assumption is to compare CCD focusing to regular camera focusing. I'm not referring here to astrophotography with film. I'm talking abou using a typical everyday camera, whether it be film or digital. Focusing such cameras is either automatic, or involves a simple pro-

cess of turning a focusing ring while observing some obvious feature of the image to identify best focus.

In other words, the assumption for regular cameras is that focusing is simple.

Focusing *can* be simple when you are doing CCD imaging, but it won't necessarily *be* simple. Consider two situations that involve both ends of the focusing spectrum. Both are drawn from my own experiences with focusing.

The first situation involves a worst-case secenario. I had just bought a 4" refractor and an ST-5C CCD camera. These were my first tools for astrophotography, and I brought a full set of useless asusmptions with me to the process. I didn't have anyone around to let me know this, however, so I proceeded to try to use the equipment as though it were a giant camera.

There was an unending stream of frustrations. The focus knob seemed incapable of making the small adjustments I needed for accurate focus. The camera took forever to download an image. The images looked terrible, and no amount of adjustments would improve them. The object would move off of the camera's CCD chip before I could even find focus! I was ready to pitch the entire collection into the nearest waste basket.

Now if I had only known a few things, I wouldn't have been so frustrated. There were a few simple truths that would have saved me much frustration:

- Rack and pinion focusers, commonly found on refractors, are not designed for ultra-fine focusing. A motorized focuser is a great asset when working with a refractor. These come in t he form of motors that drive the refractor's own focuser, or add-on Crayford-style focusers with motors. Either approach gives you much finder control over focus position, and takes the hassle out of focusing a refractor. Even oversized focus knobs are a big help.

- Most camera control software has a feature that will speed up your focusing session. Instead of downloading the entire image every time, you can download a small portion of the image, called a subframe. The subframe downloads in a fraction of the time needed for a full frame. This streamlines the focusing process, but you have to know it exists to look for it.

- Unlike a conventional photograph, a CCD image starts out as a mess. You have to take steps to reduce the noise. These steps are unlike anything required with a conventonal camera. These include esoteric things like dark frames, bias frames, and flat-field frames. These mysterious frames can make the difference between garbage and beauty, and they are well worth learning about.

- It is very important to have a good polar alignment if you are going to image. This is true even if you are taking very short exposures, such as of the moon or planets. Not only does a good polar alignment help you take longer exposures, it keeps objects on the CCD chip during the time it takes you to focus. Of all the frustrations I expierienced in my first attempts at imaging, the failure to polar align was my silliest. When I finally started to take the time to get good polar alignment, I wished that I had learned to do this sooner.

The bottom line is that you probably have some assumptons of your own. You don't know in advance how they might trip you up as you learn how to make images with a CCD camera. Keep an eye out for these assumptions any time you start to feel really frustrated. The problem might well lie with your hardware or software, but it also might lie with your assumptions about how things should work.

Sometimes, when you enter a new field like CCD imaging, your assumptions are going to get turned on their heads. When this happens, take a deep breath, and ask yourself if there isn't a completely different approach available to solve the problem. Learning to see with new eyes is more than using the CCD camera to expand your vision. It's also the process of finding creative solutions to the various problems that crop up, especially in the early part of your CCD career.