Section 3: Software-Assisted Focusing

If you have followed the instructions on focusing by eye in the preceding section, you have probably noticed that when you get very close to focus, changes in focuser position have less and less visual impact on the star you are using to achieve focus. However, being out of focus even a little will lend a soft look to your overall images. Bright stars don't show focus as clearly as dim ones do, at least not to the eye.

Short of taking five-minute full exposures to learn how good your focus really is, there is a better way to check your focus. Most camera control software includes special features that make it easier (if not always easy) to locate the best possible focus position.

The types of focusing aids you will find in camera control software include:

- Numeric readout showing the brightness of a star
- Graphic representation of the brightness of a star
- Numeric readout showing the width of the star's image

The two most commonly used software aids that include these features are Brightest Pixel, and Full Width at Half Maximum (commonly abbreviated as FWHM). CCDSoft version 5 has introduced a combination of these (and a few other) factors, called a Sharpness value. I'll have more to say about that later.

In addition, I have some detailed advice on using the dimmer stars in combination with the bright ones to achieve an exceptionally fine focus.

Brightest Pixel Focusing

The concept behind brightest pixel is simple: the better the star's light is focused, the tighter and smaller the image will be. More photons are hitting a smaller area on the CCD chip. As a result, the pixels at the center of the star's image get brighter as you get closer to focus.

Most camera control software will show you the value of the brightest pixel during focusing. In theory, you can simply watch this number, and the point at which the number is greatest represents the best focus.

That's the theory. The practical application of brightest pixel is a different story. Stars twinkle, and that twinkling is the bane of the CCD astrophotographer. Not only does it spread out the light, making stars fatter and less point-like, it also causes random changes to the brightness of a star during any given exposure. Longer exposures can help with this, but at the cost of sharpness. Longer exposures help even out the variations, but they also spread out the star images making focus more challenging in a different way.

You can still get good results with brightest pixel focusing if you keep a few things in mind:

- The random changes in the star's brightest pixel value are greatest when the star is at best focus. If the value of the brightest pixel jumps from 34,000 to 43,000 from one exposure to the next, you are likely close to best focus.
- Combine brightest pixel with visual observation. If you have two focus positions that show rapid variations in brightest pixel, use the techniques described in the section on visual focusing to help you figure out which one is the closest to best focus.
- Take more than one exposure at a given focus position, and average the results. For example, if three exposures at focus position #1 yield brightest pixel values of 1,300, 1,400, and 1,450, that's an average value of 1383. If focus position #2 yields values of 1250, 1475, and 1495, that's an average value of 1406, so position #2 is the better focus position.
- Make sure that your brightest star doesn't saturate the chip during the exposure. If the value creeps up toward saturation for your camera, shorten your exposure. Saturation is often not the maximum possible value; see chapter 6 for information on calculating your saturation level.
- Brightest pixel works with almost any star. You can focus using dim stars if you need to; the brightest pixel technique works whether the values are a few hundred, or tens of thousands. A very dim star, however, will not work as well due to the fluctuations from atmospheric turbulence.

Figure 2.3.1 shows brightest pixel readings from focusing session using the CCDOPS camera control program from SBIG. "Peak" refers to the brightest pixel. "Planet" refers to the focusing mode in use; this is described in the section "Subframe Focusing" below. To be certain that you are comparing the same star, use the X and Y coordinates in this dialog to confirm the position of the brightest pixel. The value of 8026 (left) was the first reading, and moving the focuser in a very small amount, and taking a second exposure, resulted in a value of 9847. This indicates that focus improved in the second exposure.

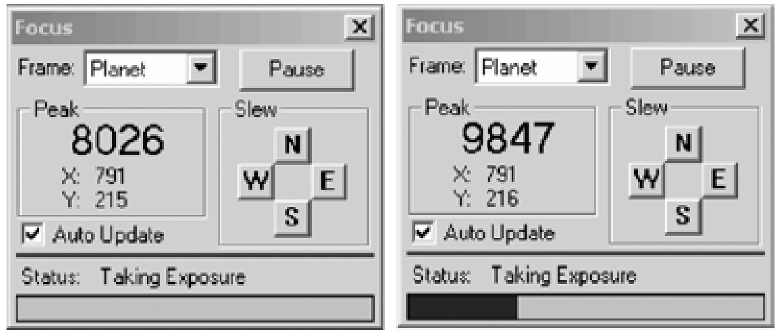


FIGURE 2.3.1. THESE DIALOGS SHOW THE NUMERIC VALUES FOR THE BRIGHTEST PIXEL IN AN IMAGE DURING TWO DIFFERENT EXPOSURES.

The most effective approach to use with the brightest pixel method is to use it in combination with other methods. The seeing may play havoc with your numbers, but if you are also visually observing the star, and perhaps using other focusing tools available in your particular camera control program, you will get better results than by any one method alone.

Figure 2.3.2 shows how MaxIm DL reports the quality of focus on the Inspect tab. The brightest pixel information is in the box labeled "Max" at bottom center. There is some additional information here as well, such as a graph and FWHM (Full Width at Half Maximum) in the X and Y directions, (covered in the next section). The graph provides very useful feedback about the state of focus. Note that when the brightest pixel is a higher value, the peak of the graph is very sharp (right), and when the focus is not perfect, the peak is a little rounded (left). The better the seeing, the more likely you are to get that nice sharp peak.

TIP: As focus improves, the brightest pixel value is increasing. Depending on your exposure time, the star may get so bright that it saturates (reaches maximum value). As you start to get close to saturation, the peak brightness will become spread out and give you a false indication of poor focus. In addition, the peak may spread out in a line due to blooming, which distorts the FWHM values in one direction. It will also flatten the top of the graph. If the brightest pixel exceeds 80% of the maximum allowable value, stop the focusing routine, shorten your exposure time (try cutting it in half), and resume. You can perform your analysis of focus quality with low brightness levels, but working at about 10-50% of saturation provides less noise and better results.

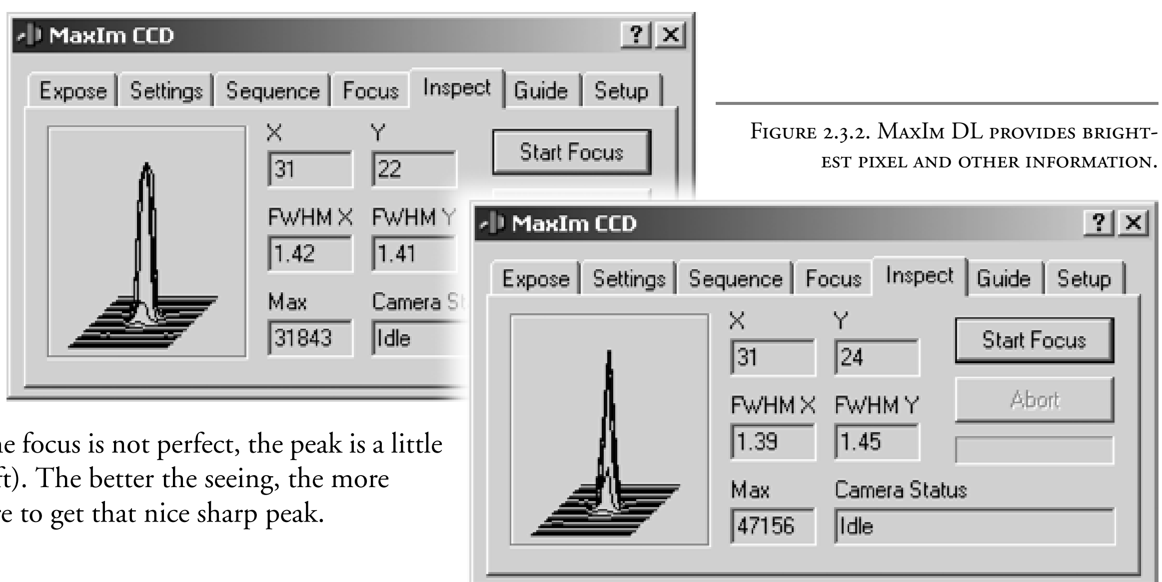


FIGURE 2.3.2. MAXIM DL PROVIDES BRIGHTEST PIXEL AND OTHER INFORMATION.

FWHM Focusing

The image of a star has a typical brightness profile (figure 2.3.3). The curve shows an idealized picture of the brightness level of the pixels across a star image. This is a bell-shaped curve, with brighter values at the top. A bell curve has most of the values falling near a central value (called the centroid of the star image). There is no definite edge to such a distribution, so it can be hard to measure the actual width of the star image.

Fortunately, there is a way to characterize the width of the star image, called Full Width at Half Maximum (FWHM). To find the FWHM, you take the highest value, divide it in half, and measure the distance across the curve at that point. The line AB in figure 2.3.3 shows the FWHM for the idealized curve.

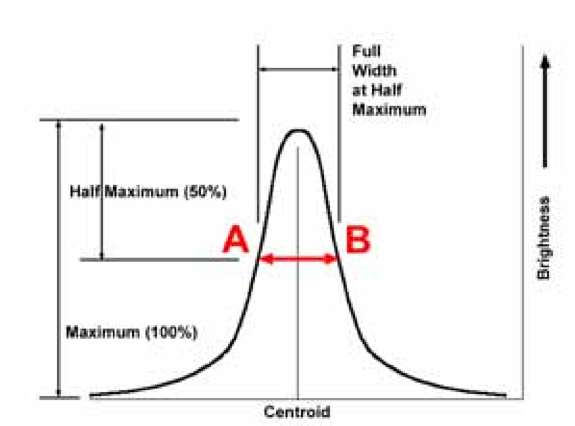
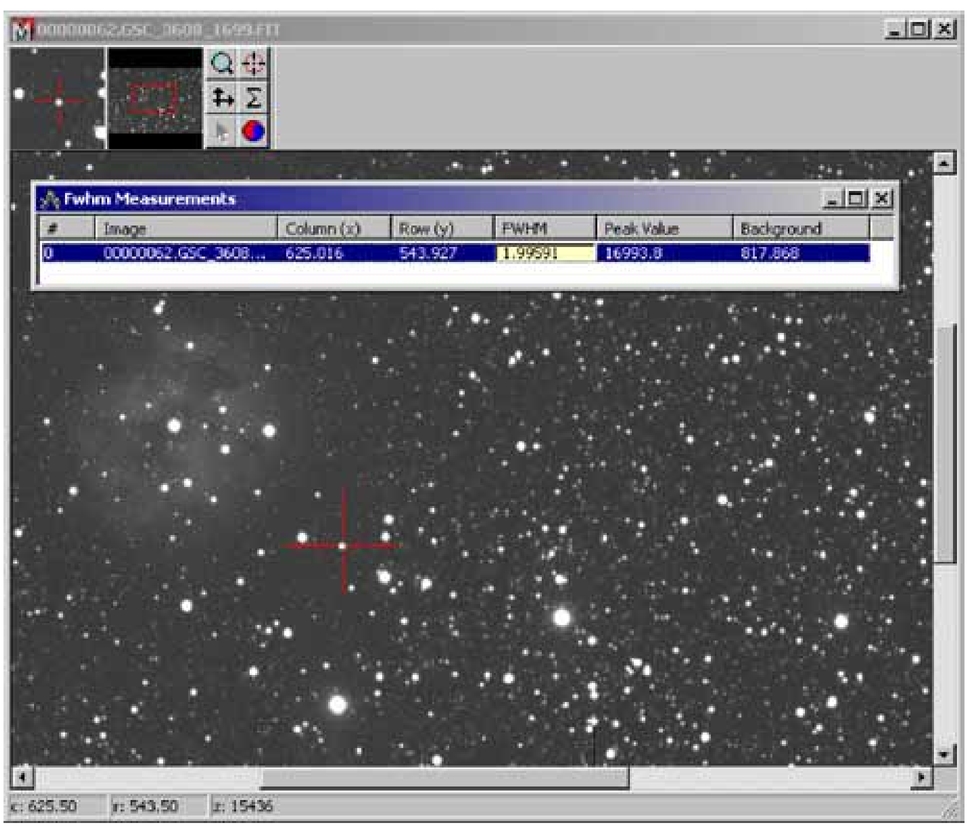


Figure 2.3.3. The brightness profile of a typical star near best focus.

Most camera control software includes some way to measure FWHM. In CCDOPs, you can use the Display | Crosshair menu choice, and then pass the cursor over a star to get the FWHM. The numbers for the vertical and horizontal FWHM are shown next to the heading "Seeing." In MaxIm DL 2.x, the Focus routine shows you two FWHM values (see figure 2.3.2). One is calculated from a vertical slice through the star image (FWHM Y), and the other is a horizontal slice (FWHM X). These values often differ by at least a small amount; if blooming occurs, they will differ by a larger amount. In version 3, MaxIm DL provides a more accurate single FWHM value.

Figure 2.3.4. Determining FWHM in Mira AP.



With Mira, change the cursor to a cross hair (right click on the cursor and choose cross-hair). Position the cursor over a non-saturated star, and use the Measure | FWHM menu item. This displays several measurements at one time in a small window, as shown in figure 2.3.4. You get values for FWHM, peak value, and background value displayed at the same time. It is useful to compare the brightness of your peak pixel against the back-

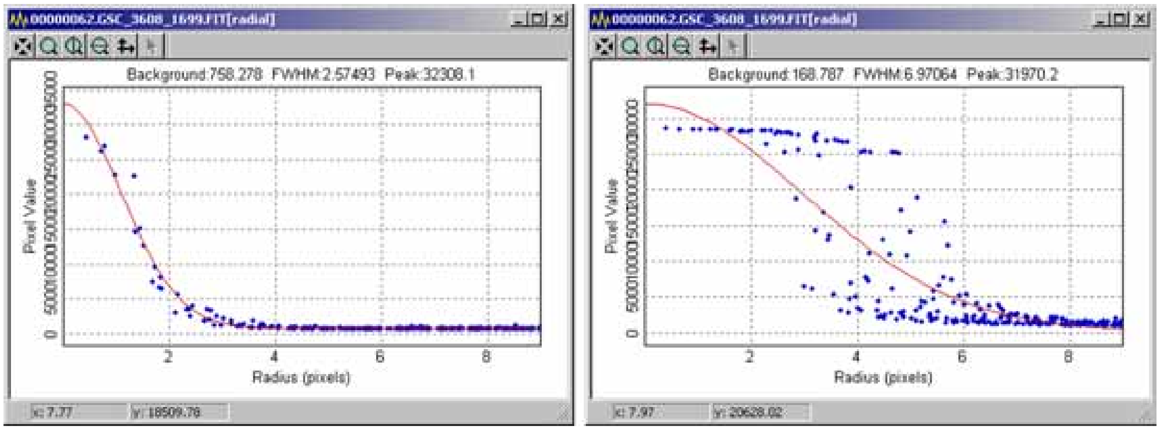


FIGURE 2.3.5. A NON-SATURATED STAR REPORTS ACCURATE FWHM (LEFT), BUT A SATURATED STAR HAS A NON-NORMAL SPREAD OF VALUES AND REPORTS AN INACCURATE FWHM.

ground. On a moonlit night, you might have a 1000-count brightness for brightest pixel, but if your background level is 800, then you aren't working with a very bright star.

The MaxIm DL method for viewing FWHM is ideal, while the CCDOPs and Mira methods are slow because you have to restart the focusing process to measure FWHM. CCDSoft v5 doesn't report the FWHM during focusing, but it does have a similar measurement called the Sharpness value that is covered later in this chapter. In CCDOPS and Mira, I rarely use FWHM because of the inconvenience. I use FWHM on a routine basis with MaxIm DL and CCDSoft v5.

Avoiding saturation when measuring FWHM is critical to success. Mira provides a radial plot of a star's brightness from center to edge (Plot | Radial Profile menu item). Figure 2.3.5 shows two examples of radial plots for stars from the image in figure 2.3.4. The plot on the left shows a non-saturated star. The FWHM is measured accurately at 2.57 pixels. In the plot on the right, the data points have a flattened, very broad top. This results in a cruve that is wider than it should be. These are classic indications that the star has saturated. The plot on the left is for the star with the cross hairs in figure 2.3.4. The plot on the right is for the bright star straight below the cross-hairs.

Table 2.1 shows some statistical information taken from a series of images during an actual focusing session. The focus position for successive images varies by a very small amount – the smallest manual change in focus I could make, as a matter of fact. A new focus image was taken after each change in focus position (see samples in figure 2.3.6), and the following values were obtained for two different stars:

Average value for star #1 – This number reflects the average of the values in a circle 9 pixels in diameter.

Max Brightness for star #1 – The brightest pixel value in the star image.

FWHM for star #1 – Taken by averaging the FWHM X and FWHM Y values in MaxIm DL.

FWHM for star #2 – Same as above, for a second star.

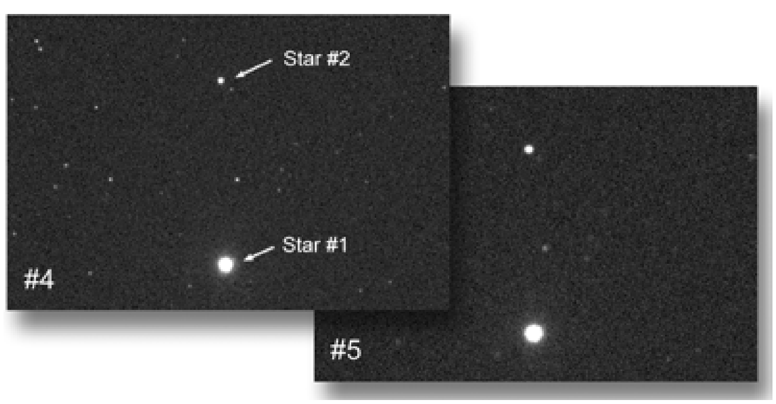


FIGURE 2.3.6. THESE ARE TWO OF THE IMAGES USED TO CONSTRUCT TABLE 2-1.

Table 2.1: Brightness and FWHM

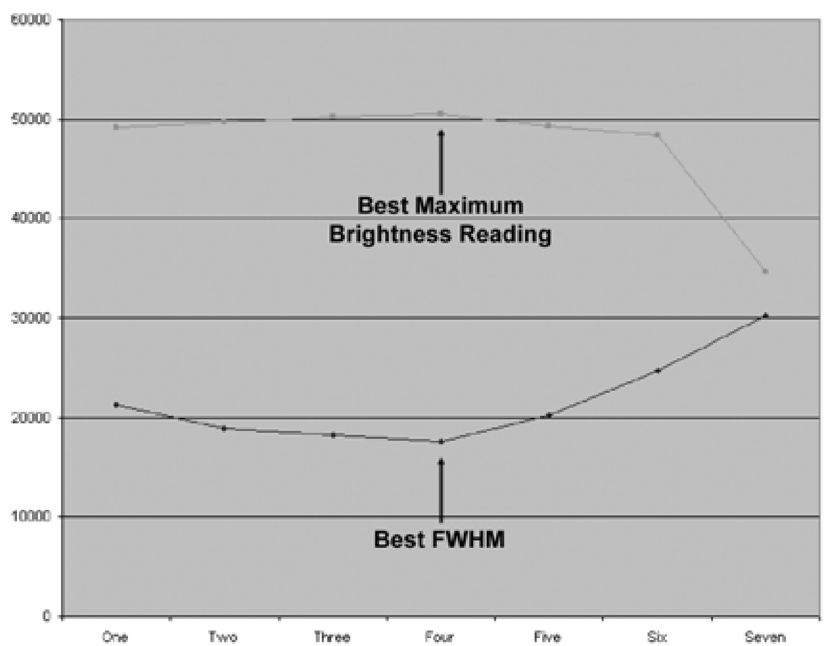
	Star 1		FWHM	
Image #	**Average**	**Max Brightness**	**Star 1**	**Star 2**
1	2222	49220	2.283	2.124
2	2037	49694	2.219	1.884
3	2208	50180	2.229	1.826
4	2275	**50421**	2.269	**1.759**
5	2124	49307	**2.213**	2.024
6	2423	48358	2.496	2.465
7	2510	34565	3.028	3.024

The brightest pixel value is for image #4. The lowest FWHM value for star #1 is in image #5, while the lowest FWHM value for star #2 is at image #4. In the original data, there was a slight amount of blooming in star #1, which was revealed by a significant difference in the FWHM for X and Y. A large difference indicates blooming and/or saturation. Because of the blooming on star #1, use star #2 to determine best focus.

Figure 2.3.6 shows the images referred to as #4 and #5 in table 2.1. Visually, image #4 looks slightly sharper, further confirming it as the right focus position. It is easy to compare images when you have brightest pixel and FWHM data handy, but it's a lot harder in real time to be sure visually. Having additional sources of data about the sharpness of an image will help you reach focus faster and with greater confidence.

Figure 2.3.7 shows a graphic representation of the data from table 2.1. The FWHM values have been multiplied by 10,000 in an Excel spreadsheet to get all values on roughly the same scale; this does not affect the relative values in each series. Note that the brightest pixel and lowest FWHM coincide on image #4. Note also that the values don't shift much right around best focus, so it takes careful work to measure the point of best focus. This is yet another reason why combining methods will work best to determine critical focus.

Figure 2.3.7. A chart showing the values for brightest pixel and FWHM in a series of images.



Subframe Focusing

Depending on the size of your CCD chip, it can take a long time to download a full frame of information. Since final focusing is always done at 1x1 binning, downloading times are at their maximum. Most camera control programs allow you to select a sub-frame for focusing so that fewer pixels are downloaded for each exposure. This greatly speeds up the focusing process. If your polar alignment is good enough to keep stars stationary for a few minutes, you can use a very small focus frame and get focus feedback practically in real time.

In CCDOPS, this technique is called Planet mode, but you use it for much more than just planets. In CCDSoft and MaxIm DL, you can select a portion of the chip at any time by clicking and dragging. This makes focusing fast and easy.

To start Planet mode in CCDOPS, select Planet as the frame size when you enter focus mode. For convenience, you can set Update Mode to Auto, and enter a delay time between exposures. Auto update tells the camera to repeatedly take exposures during the focusing session. The delay gives you a pause in which to adjust focus position. For your first focusing sessions, you may wish to leave auto update turned off so you can work at your own pace.

Figure 2.3.8 shows what the CCDOPS Planet mode looks like in action. Two star images are readily visible, and they are very far out of focus. The Focus dialog is at upper right, and it remains visible throughout the focusing session. It shows that Planet mode is active. When you first enter Planet mode, CCDOPs will take a full-frame exposure of the length you requested at 1x1 binning, and display the image as in figure 2.3.8. It then pauses, and you drag out a rectangle to show the area you want to use for focusing. You must take the full-frame exposure at 1x1; you cannot image at 3x3, drag out the rectangle, and then jump to 1x1. Other packages, such as MaxIm DL and CCDSoft v5, do allow you to switch fluidly from one bin mode to another. CCDSoft is slightly better in this regard.

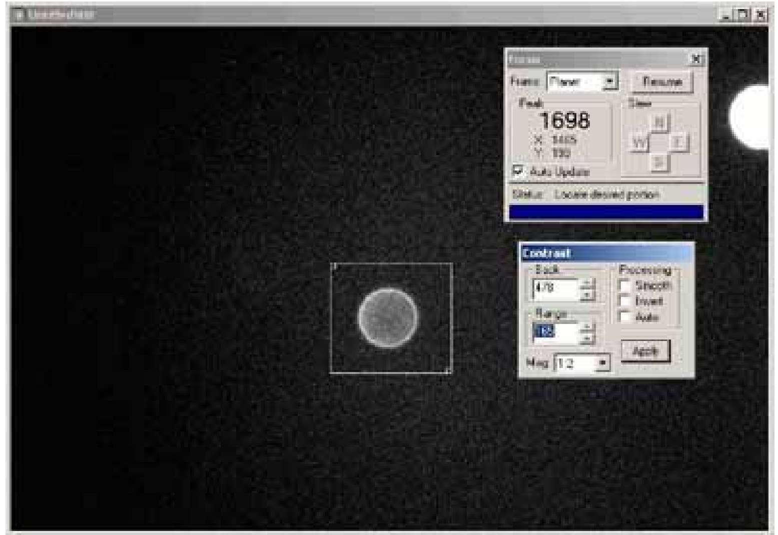


FIGURE 2.3.8. CCDOPS PROVIDES A PLANET MODE THAT ALLOWS FOR FAST, EFFICIENT FOCUSING.

TIP: Depending on the accuracy of your polar alignment, you may need to allow more room around the star you will be using for focusing. Unless the mount is extremely well aligned to the celestial pole, the star will drift during the focusing session. If the box is too small to accommodate the drift, the star will move out of the subframe and you will have to restart focusing.

Once you have set the rectangle to the size and location you want, click the Resume button at the upper right of the Focus dialog. The camera will take the first exposure. If you chose automatic update, you can adjust the focus position during the delay. To change the delay in CCDOPS, restart the focusing session.

The best overall procedure for CCDOPS focusing:

1. Use Dim mode to get a rough focus. Focus visually, and get the smallest, best-focused star image possible. Dim mode uses a 3x3 or 2x2 bin mode, so will probably still be a little off.
2. Switch to Planet mode for final focusing. Use the visual cues outlined in the first part of this chapter and the brightest pixel method to confirm when you have best focus.
3. Continue focusing until you have definitely passed the point of best focus, then back up to it again.

In figure 2.3.8, the stars are way out of focus, so I'm not really following my own advice! The Peak value in the Focus dialog is only 1698. However, there's no reason not to use Planet mode or a subframe for all of your focusing, and if your mount is well aligned to the celestial pole, and doesn't drift much, you'll be able to use Planet mode comfortably – the star won't drift out of view.

Focus Analysis

Figure 2.3.9 shows the brightest pixel values for a series of 24 images during a focusing session. This sequence is fairly typical of how things go when you are using a camera for the first time – it's hard to know where focus position is going to be. That's why the brightness values at far left are so low -- the star was very far out of focus. The frames numbered 1 through 5 are described a little further on.

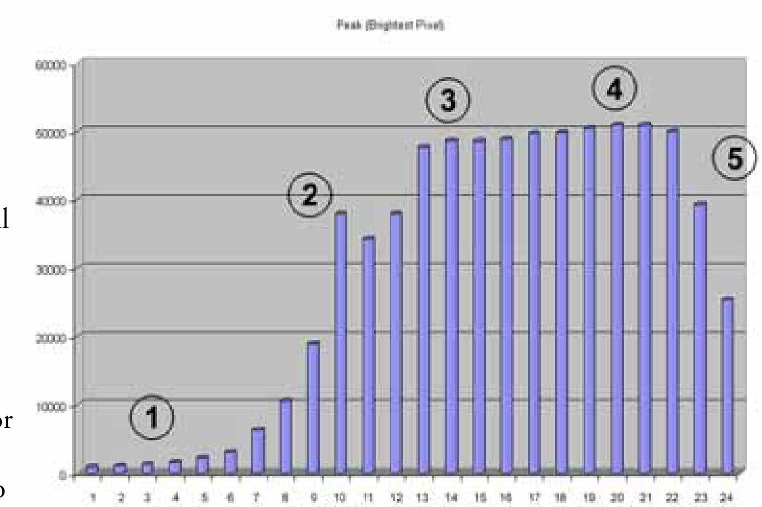


Figure 2.3.9. Brightest pixel values for a series of 24 exposures during a focusing session. See text for a description of the five key points in the focus process

The point of focus for a CCD camera will usually be different than the point of focus for your eyepieces. There are parfocal eyepieces that will come to focus at the same place as a CCD camera, such as the Software Bisque IFocus. You can make your own eypeieces parfocal using a ring described later in this chapter.

If you can point reliably at a star, such as with a goto mount, it will be easier to put objects on the chip. A bright star (mag 3 or brighter) will be visible even if you are extremely far out of focus. If your finder is very well aligned, it can also help you put a star on the chip. But if you have a telescope with an internal focuser, such as an SCT, an eyepiece that is parfocal with your camera can make it easier to get close to correct focus. If you can measure the focus position, as on a refractor, you can easily return to the CCD focus position.

TIP: If you have an SCT, you can count the turns of the focus knob required to reach focus with the camera. If you have a refractor, consider cutting a piece of plastic that is the same length as the focuser extension to make it easier to find the right starting position in the dark. Anything you can do to quickly find the general area of the correct focus position for CCD will help you speed up your focusing session.

It's worth pointing out a few characteristics of the curve in figure 2.3.9; the numbered positions in the figure correspond to the points that follow:

1. If you start very far out of focus, the value of the brightest pixel will initially change very slowly, then speed up as you get closer to focus. This can make it hard to determine the correct direction initially. The out-of-focus star image will shrink noticeably as you improve focus.
2. Don't' be shocked, surprised, or give up just because you suddenly get a lower value during the focusing session. Many things can cause a lower value – a cloud may have temporarily moved over the star, or the wind may have smeared the star out a little more than usual. Don't panic; if the star doesn't look focused, it isn't!
3. Once you get close to best focus, start making smaller and smaller changes to focus position. Sneak up on the best focus with small steps. Keep going until you are sure you have best focus.
4. The highest value is the best candidate for critical focus. If your focuser has digital readout, you can make a note of your best focus and return to it. Check the brightest pixel value to be sure you are at the correct position. If your focuser has backlash (free play when reversing direction), the numbers

will probably not match exactly. You may have to spend some time estimating how much movement gets used up in backlash in order to use the numeric readout to return to best focus. Develop a feel for how the focuser behaves when reversing direction.

5. Once you are past best focus, values will drop off rapidly. When you are first learning how to focus, it is a good idea to go too far. Way too far is OK. You want to develop your sense of where best focus is, so don't hesitate to go back and forth, back and forth, until you get a feel for where it is. Invest a little time now to master the best focus position, and reap dividends forever after. Amaze your friends with your ability to bring complex equipment to a complete and safe focus.

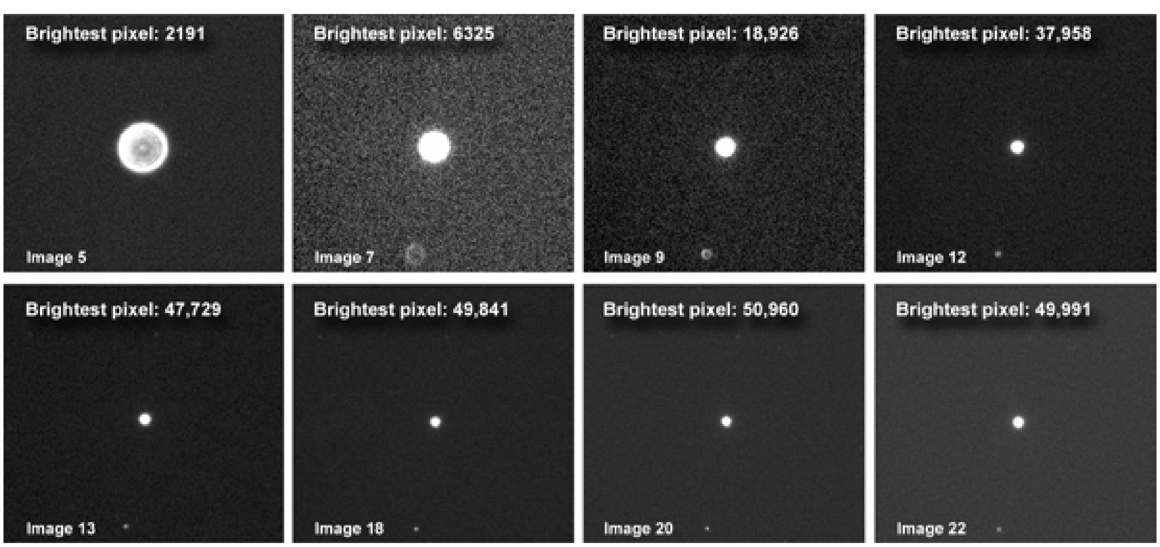
TIP: I've mentioned this elsewhere, but it bears repeating right here: if you aren't sure if you are at best focus, take 2, 3 or more exposures to see how the brightest pixel values changes. Average them, on paper or in your head. If the seeing is poor, you will see large variations in the brightest pixel values, and there will be a wide range of positions where best focus might be. Try to judge where the middle of that range is, and set your focus at that point (interpolation). If the seeing is very good, you will have much better control over the situation, and brightest pixel values will be more consistent and useful in finding the exact spot of critical focus. Oddly enough, when the seeing is good, the brightest pixel values will be so high that they may actually fluctuate more than they will with poor seeing. However, when the seeing is good, this fluctuation will be most pronounced right around critical focus, so you can use this to help you determine where the best focus position is.

Figure 2.3.10 shows eight of the images I used to create the chart in figure 2.3.9. Each is labeled with the value of its brightest pixel, and the image number is from the sequence of 24 images charted in figure 2.3.9. I pulled out these eight images because each of them shows something useful about the focusing process.

Image 5 – This image is taken early in the focusing sequence. You can clearly see the diffraction rings typical of a good scope when a star image is out of focus and at high magnification. The brightest pixel value is far lower than what it will eventually be when the image is in focus, just 4% of its final value.

Image 7 – This image is in somewhat better focus. There is a second star appearing – as you improve focus, dimmer stars become bright enough to stand out against the background. The background level appears to be different, but that's not the case. The camera control software has adjusted image contrast automatically. You can turn off this feature using the Auto checkbox in the Contrast window, and if you are using the visual

Figure 2.3.10. Eight images from the focusing series shown in figure 2.3.9. See text for details.



appearance of the star for focusing, turning off automatic adjustments can help you track what's happening more consistently.

Image 9 – The star image is smaller and the brightest pixel value is now much higher, about 35% of its final value. The dimmer star is giving you clear feedback that the image is not in focus, because you can still make out its diffraction rings. **It is ideal to have a mixture of dim and bright stars in the focus window, because each type of star provides different kinds of clues about the quality of focus.**

Image 12 – In this image, the brighter star is now quite small, and actually appears to be very close to focus – but it is not! The dimmer star gives better feedback here: although it is now very small, it still has not become very bright. The visual clues are becoming more subtle, but the brightest pixel value is still only about 75% of its final value. Despite how much better things look, we have a long way to go yet!

Image 13 – In this image, focus is clearly better. Two very dim stars can be seen just below the text "Brightest pixel." You may or may not be able to see them printed in the book – the printing process can loose subtle details. One of the new stars is below the letter "B," by about the height of that letter; and the other is below the colon following the "l," at about the same vertical position. The dim star at the bottom is a bit sharper, with a hint of a bright point within the tiny cloud of light. The bright star is just ever so slightly smaller; you would need to view the image at 400x or even 800x and count pixels to see this, however.

Image 18 – This image looks like it is very, very close to focus – and it is, but it is not quite there yet. The brightest pixel value is now 98% of its best possible value, and you might be tempted to stop here because the image looks very good. Even though we are very close to focus, we are not at focus! The dim star at the bottom is still a little cloudy, but has a very clear bright center. The two very dim stars at the top are a little bit clearer in this image, but still quite dim. This is why I recommend going past focus before you settle on what the best focus is like. You have to see how good you can get the focus on any given night to know when to stop, and the only way to be sure is to go past the best focus position.

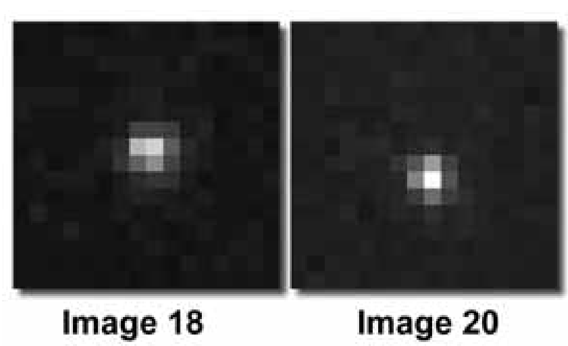
Image 20 – This image shows critical focus. There are two important changes from image 18: the brightest pixel value is now consistently above 50,000; and the dim star at the bottom is a perfectly clear dot, with no fuzziness, no cloudiness at all that would indicate any amount of out-of-focus. The two very dim stars are also a bit more visible. See figures 2.3.12 and 2.3.13 for magnified views of the dim stars in this image.

Image 22 – In this image, we have gone a bit past perfect focus. The dim star is now slightly fuzzy, and the two very dim stars near the top are just barely visible.

TIP: This example uses the SBIG camera control software, CCDOPS, to illustrate how to analyze a star image's brightness for best focus. You could just as easily use a program like MaxIm DL, and use both brightness and FWHM data to determine best focus. FWHM will show the same variations, and the same overall pattern as CCDOPS. However, having both terms available to cross-check focus gives you a better shot at finding the critical focus position.

Figure 2.3.11 shows extreme blow-ups of the dim star at the bottom of these images. The left side of figure 2.3.11 shows a magnified view of image #18. The star is so small that it *looks* like it is fully illuminating just a single pixel. However, upon close examination, you can see that it partially illuminates the adjoining pixels. Other surrounding pixels have a small amount of illumination, and the star is at least partially illumi-

Figure 2.3.11. The dim star at left is slightly out of focus; the brightest pixel isn't much brighter than surrounding pixels. The star at right is very well focused; the brightest pixel is much brighter than the surrounding pixels.



nating a box of pixels that is five pixels wide, and four pixels high.

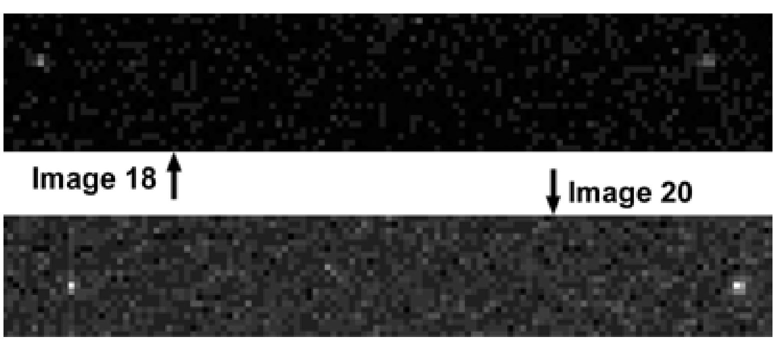
Now look at the star in image #20 (right of figure 2.3.11). The central pixel is much brighter than the surrounding pixels. And the box which the star is illuminating is now only 3x3 pixels. All of this points to better focus in image 20. Now you know what I mean by subtle differences!

Figure 2.3.12 shows more evidence. These are the very dim stars at the top of the images. In image 18, the brightest pixel isn't much different from the surrounding pixels. In image 20, the brightest pixel is much brighter than the surrounding pixels. It really stands out, demonstrating the value of dim stars when focusing.

You won't always have dim stars that match your pixel size this closely – it will vary with the focal length of your telescope. A long focal length or poor seeing will smear the dim stars and make them less useful in assessing focus quality. But when these one-pixel stars are available, they can help you reach critical focus on nights when the seeing is truly excellent, when critical focus is so important.

TIP: In poor or average seeing conditions, the air will not be steady enough to bring the dim stars to such perfect points. But when the seeing is better than average, you can achieve a very exact focus by combining information about the brightest pixel in a bright star, the appearance of a dimmer star, and the visibility of any very dim stars. And whatever the seeing conditions, dim stars offer you yet another way to analyze the quality of your focus position.

Figure 2.3.12. In focus (image 20, bottom), dim stars are brighter.



Focuser Issues

The focuser built into your telescope is an important factor in your ability to get to perfect focus. As you get close to focus, you need to make very, very small adjustments to focus position. The shorter the focal length of your telescope, the smaller the moves you will need to make.

Your ability to move your focuser in very small increments will vary from telescope to telescope. Some telescopes, such as refractors, may have fairly gross focus movement, while others, such as the 9.25" Celestron SCT, have geared focusing or digital readout. If you can't get the degree of fine focusing you feel you need, there are aftermarket focusers that can be a good solution. There are two-stage focusers (coarse and fine); motorized focusers (some work great, others don't help much because they have so much backlash); and DRO (digital readout) focusers. See the last section of this chapter for information about these alternative focusing mechanisms.

If all of this focusing information seems like overload, take heart! There are even better ways to focus than what you've seen so far. Nonetheless, focusing with nothing but your eyes and the camera software is a worthwhile skill. As you get good at focusing, you may well return to your roots and focus quickly and easily with nothing more than you've seen so far. You develop a sense for where best focus is over time, and the need for clever aids goes away after a while. As I've said before, and will say again many times, the time you spend focusing is time well spent. And since a variety of factors can conspire to change the point of focus through the course of the evening, the ability to focus quickly and effectively will make it easier to bite the bullet and refocus often.